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THE EFFECTS OF AGRICULTURAL PESTICIDES IN THE AQUATIC ENVIRONMENT, IRRIGATED CROPLANDS, SAN JOAQUIN VALLEY

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California University

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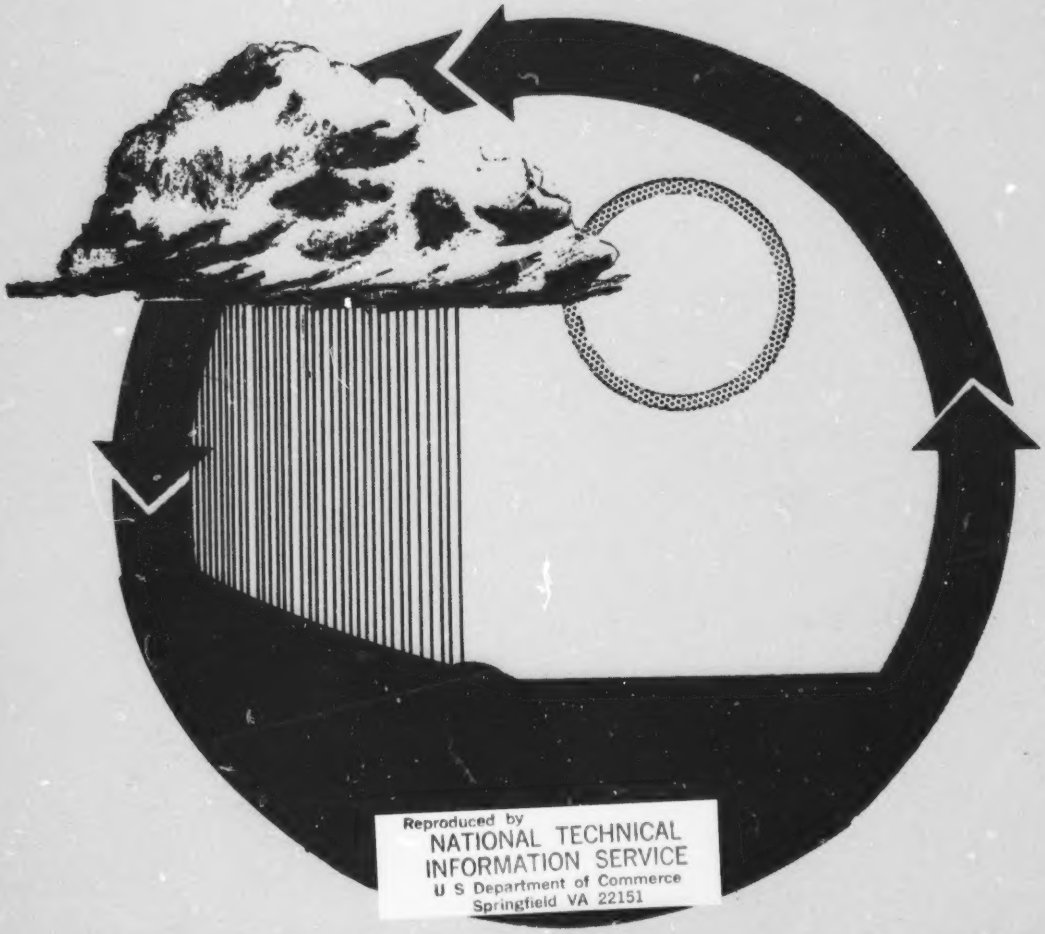

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THE EFFECTS OF AGRICULTURAL PESTICIDES IN THE AQUATIC ENVIRONMENT

IRRIGATED CROPLANDS, SAN JOAQUIN VALLEY

295

PESTICIDE STUDY SERIES - 6

THE EFFECTS OF AGRICULTURAL PESTICIDES IN THE AQUATIC ENVIRONMENT, IRRIGATED CROPLANDS, SAN JOAQUIN VALLEY

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This report has been reviewed by the Office of Water Programs of the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, or does mention of trade names or commercial products constitute endorsement or recommendation for use.

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Summary

Estimates of the environmental impact of pesticides in the San Joaquin Valley of California are limited by the amount of reliable information available on pesticide use in the area, the extent of scientific knowledge on the effects of pesticides released into the environment, and the applicability of this knowledge to field conditions in the valley. Achieving an optimum balance between the competing needs for food and fiber production, on the one hand, and environmental quality, on the other, will further require an understanding of the conflicting interests and responsibilities bearing on pesticide use in the region, and the probable impacts of alternative practices and policies.

This present case study attempts to assess the impact of agricultural pesticides on the aquatic environment of the San Joaquin Valley, and to point out some possible courses of action. The following approaches were used: 1) University scientists and officials of federal, state, and county agencies were interviewed for information and expert opinions. 2) The literature of pesticides was surveyed and reviewed, relying primarily on the unique collection, files, and services of the Environmental Toxicology Library of the Food Protection and Toxicology Center at the University of California at Davis. 3) Information of pesticide use was retrieved from a data bank containing files of detailed records in machine-readable form.

The study embraces the following topics; 1) description of the study area; 2) inventory of uses; 3) application techniques and types of pesticide material being used; 4) routes of pesticide entry into the aquatic environment; 5) the degradation, metabolism, and persistence of pesticides in the aquatic environment; 6) impacts of pesticide pollution on the aquatic environment; 7) alternatives to pesticides for pest control; 8) laws and regulations governing agricultural pesticide use in the San Joaquin Valley.

Description of the Study Area

A large part of California's land mass is in the shape of an oblong bowl with a single huge central valley formed by the Sacramento Valley, in the north, and the San Joaquin Valley in the middle and south. The Sacramento River and its tributaries flow generally southward until they meet the San Joaquin River and its tributaries, flowing generally northward.

From their confluence, in the Sacramento-San Joaquin Delta, these waters flow westward and reach the Pacific Ocean through the Golden Gate. The southern part of the San Joaquin Valley has no natural drainage outlet.

In spite of a heavy demand for irrigation water for agriculture in the central valley, the problem is not one of water insufficiency but of maldistribution: most of the rainfall in the valley is in the north and east but most of the agriculture is in the south and west. To supplement the natural sources of water available in the San Joaquin Valley, the California Water Project transports hugh quantities of surplus water from the delta to the San Joaquin Valley.

Over the years, an elaborate system of canals and aqueducts has been constructed in the San Joaquin Valley, and this region is now the largest contiguous area of irrigated cropland in the world. The valley's productivity is phenomenal, and three of the valley's eight counties are the top three counties in the nation in the value of their farm production.

Inventory of Uses

To maintain the high quality of their agricultural products, and a high level of productivity, the farmers of the valley depend heavily on pesticides to combat insects, weeds, and diseases. Through collaborative efforts of the University of California and the California Department of Agriculture, detailed records of pesticide use are now available. These records, in machine-readable form, tell the pesticide used, commodity of crop, target pests, location (county, township, range, and section), date of application, acreage, mode of application (areal, ground, or other), concentration of active ingredient, and rate of application per acre. They show that over 1.7 million pounds of toxaphene and 0.8 million pounds of DDT were used in agriculture in the valley in 1970. Parathion was the top organophosphorus pesticide used, with 590,000 pounds applied to 460,000 acres. This highly toxic substance was applied more frequently than any other pesticide, with 10,835 recorded instances of agricultural use in the study area in 1970. Carbaryl was the top carbamate insecticide used, and 2,4-D was the top herbicide.

Analysis of 48 of the principal pesticides used in agriculture in the San Joaquin Valley revealed that the pounds of pesticides used tends to be concentrated on relatively few crops. Less that half the crops accounted for more than 98% of the pesticide use, and cotton alone accounted for 30% of the total. This latter statistic might prompt one to wonder about the influence of government price-support policies on pesticide use.

Soil fumigants (including Telone, D-D Mixture, methyl bromide, and chloropicrin) are used in very large quantities for nematode control. The application rates are high (on the order of one hundred pounds or more per acre), compared with typical application rates for other pesticides of one to three pounds of active ingredient per acre. Thus, these compounds rank high in lists of pounds of pesticides used but do not rank high in lists of acreages treated. Also, in the analysis of pests on which the 48 major pesticides were used, nematodes ranked first out of 169 target pests on the basis of pounds of pesticides applied, followed by lygus, mites, worms, weeds, aphids, bollworm, scales, and thrips, in that order.

A study of pesticide use in 1948 through 1968 in Kern County (in the valley) showed a long-term trend of decreasing use of organochlorine insecticides and increasing use of organophosphorus and carbamate compounds. Use in Fresno County in 1968 and in 1970 showed a continuation of these trends.

Application Techniques and Types of Pesticide Material being Used

Of the major pesticides applied in the valley, approximately 50% by weight is applied from aircraft. In terms of acreage, approximately two-thirds is applied aerially. The danger of contamination of nontarget area by drift, however, relates more to droplet or particle size and to micrometeorological conditions than to the choice between aerial and ground application.

Next to droplet size, the most important factor influencing drift is the climate in the immediate locality of application. In practice, spraying by ground or aerial application is not recommended in winds of 10 miles per hour or more, in periods of temperature inversion, or in generally turbulent weather.

Only after these factors are taken into consideration is it meaningful to generalize that the likelihood of drift of applied pesticides increases in the following order: soil injection; hydraulic ground spray; air-carrier ground spray; aircraft.

As elsewhere, pesticides in the valley are used in a large number of formulations: emulsifiable concentrates, wettable powders, dusts, sprays, pellets, etc. The most common formulation types used in the valley are emulsifiable concentrates and wettable powders, both diluted with water before use.

Figure I shows the quantities of three organochlorine compounds--toxaphene, DDT, and kelthane (dicofol)--used in agriculture in each month of 1970, for all eight counties of the San Joaquin Valley. The use of all three pesticides is most concentrated during May-September. A combination of the first two is commonly applied as an insecticide on cotton. Kelthane, a miticide, is chemically related to DDT but is much less persistent. The fact that the time of most concentrated use of these and many other pesticides coincides with the months of intense sunlight in the San Joaquin Valley reduced their ability to persist in the environment.

Figure II shows the monthly agricultural use of the two top organophosphorus insecticides, ethyl parathion and malathion, in the eight counties of the valley. Use of malathion peaks in the summer months, but it has a longer period of heavy use than do the organochlorine compounds. The use pattern of parathion has several peaks, reflecting the wide variety of crops and insect pests for which it is used.

Figure III shows the pattern of use of two herbicides in agriculture in the San Joaquin Valley in 1970. The use of herbicides is concentrated in the early months to eliminate undersirable plants before they can establish themselves as competitors for space, water, and nutrients. Their use beyond early spring is also limited by the hazards to desirable plants (crops) resulting from application in summer.

Routes of Pesticide Entry into the Aquatic Environment

As shown in Figure IV, pesticides reach the aquatic environment via various routes of transport: 1) Runoff is ordinarily considered to be the major route of pesticides into the aquatic environment. The amount of pesticide carried by runoff is influenced by: a) the nature of the pesticide; b) the extent of its use; c) edaphic considerations; d) climate; e) topography; and f) practices of land management. Thus, heavy rainfall immediately after application of a pesticide can transport a great deal to surface waters, although soils that are high in humus will yield less than sandy soils, and pesticides with short persistence will pose less of a threat than the more persistent pesticides.

FIGURE I

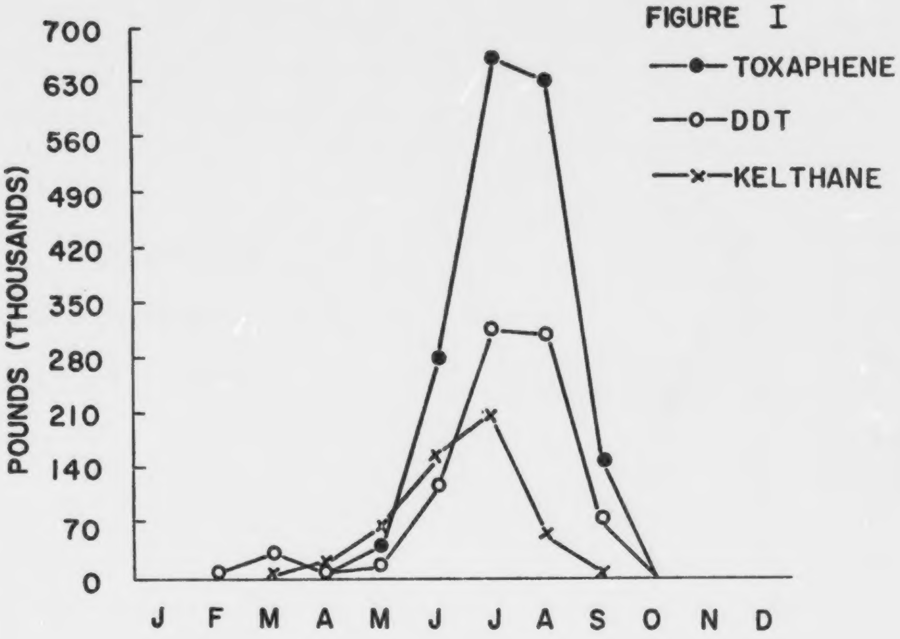
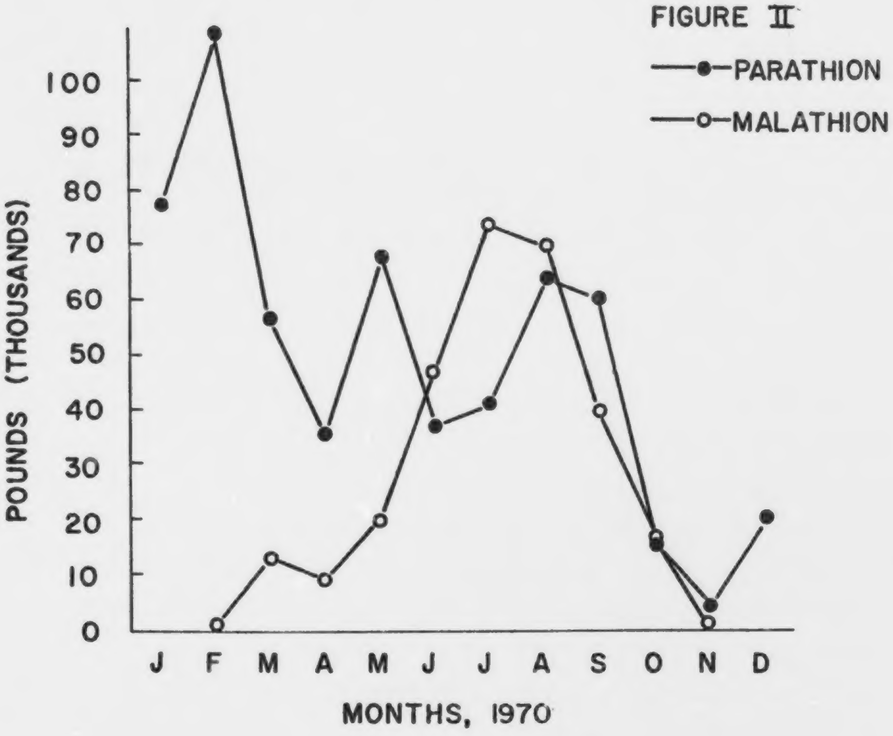


FIGURE II



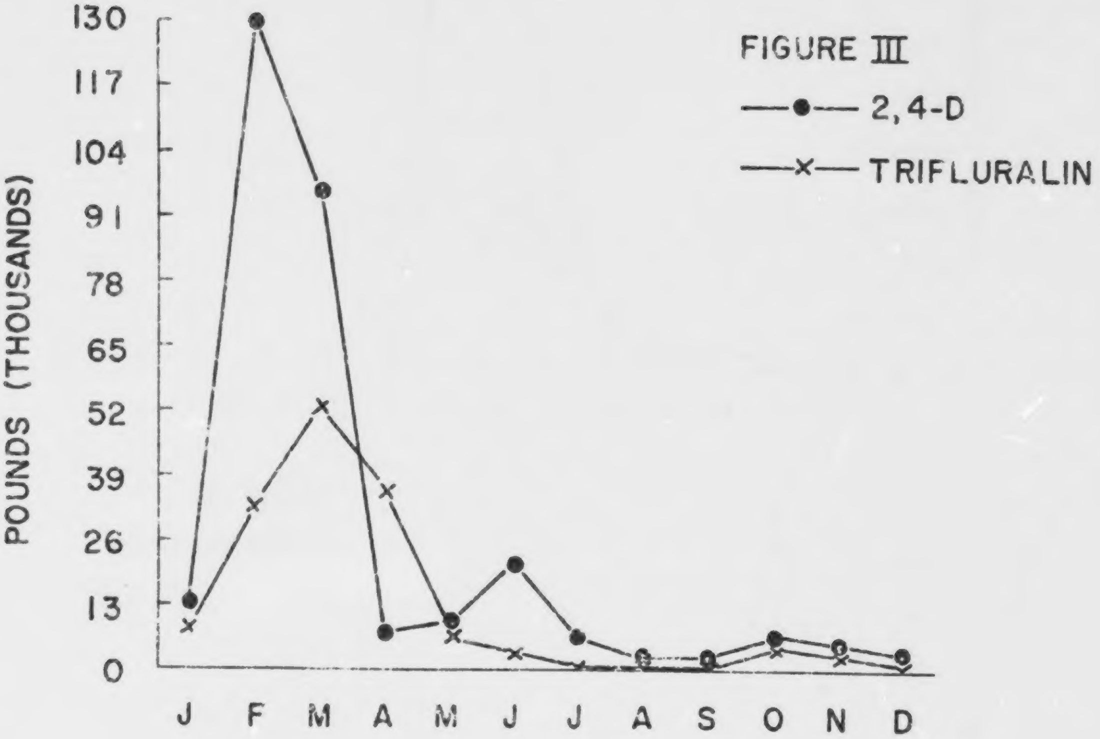


FIGURE III
—●— 2,4-D
—×— TRIFLURALIN
POUNDS (THOUSANDS)
130
117
104
91
78
65
52
39
26
13
0
J
F
M
A
M
J
J
A
S
O
N
D

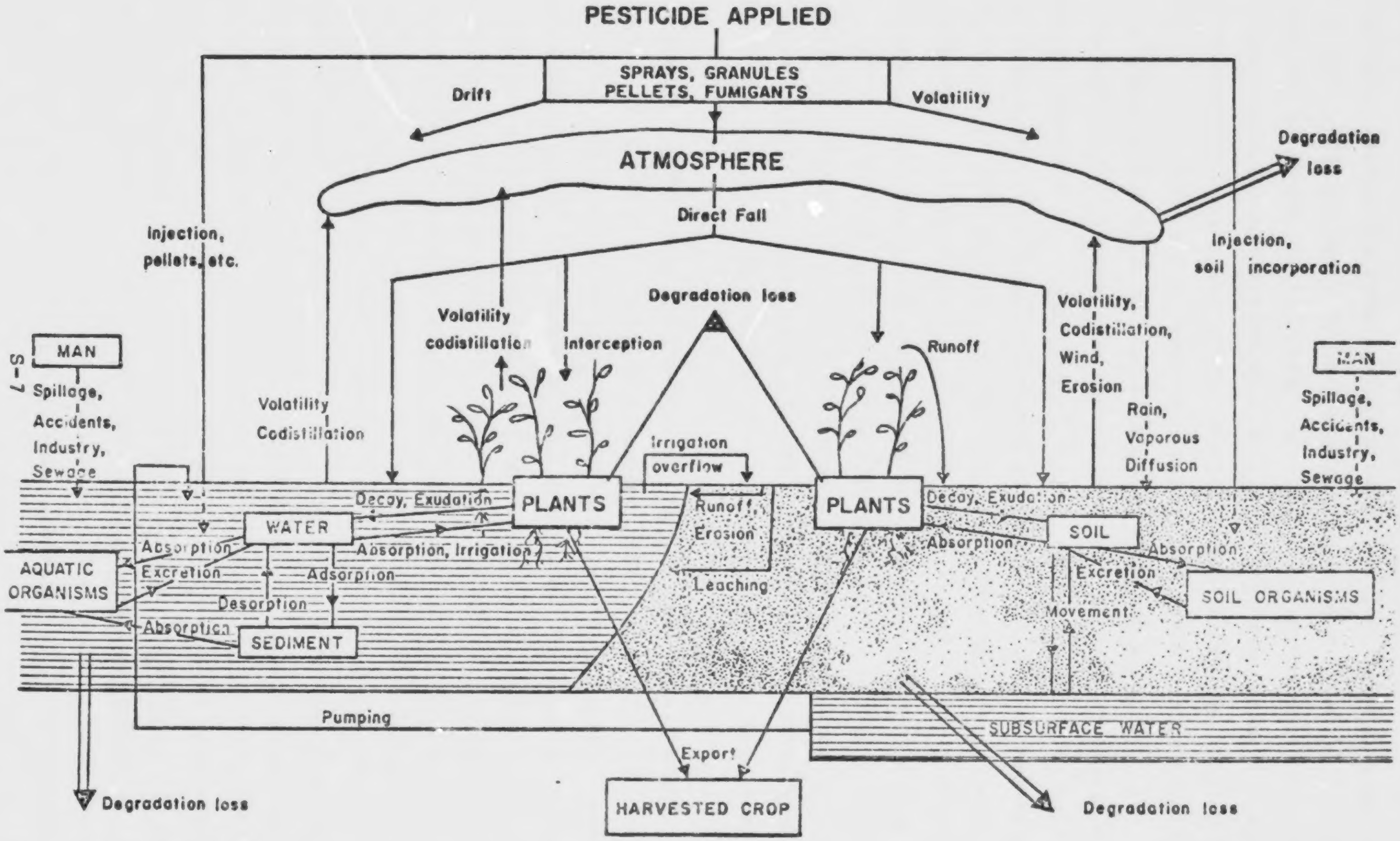

PESTICIDE APPLIED
SPRAYS, GRANULES
PELLETS, FUMIGANTS
Drift
Volatility
ATMOSPHERE
Degradation loss
Direct Fall
Injection, pellets, etc.
Injection, soil incorporation
Degradation loss
Volatility codistillation
Interception
Runoff
Volatility, Codistillation, Wind, Erosion
Rain, Vaporous Diffusion
MAN
Spillage, Accidents, Industry, Sewage
Volatility Codistillation
Irrigation overflow
MAN
Spillage, Accidents, Industry, Sewage
Decay, Exudation
PLANTS
PLANTS
Decay, Exudation
WATER
SOIL
Absorption
Absorption, Irrigation
Runoff, Erosion
Absorption
Absorption
AQUATIC ORGANISMS
Excretion
Adsorption
Leaching
Excretion
SOIL ORGANISMS
Desorption
Movement
Absorption
SEDIMENT
Pumping
SUBSURFACE WATER
Export
Degradation loss
HARVESTED CROP
Degradation loss

Figure IV Pesticide Cycling in the Environment

Studies of runoff in areas of high rainfall and varied topography do not apply to the level San Joaquin Valley, with its annual rainfall of only about 10 inches. Even so, the irrigation of crops can give rise to pesticide runoff in some cases. A report that agricultural runoff is the greatest source of pesticides reaching California waters has not been confirmed in the valley. Detailed studies of erosion in the area have recently been initiated by the River Basin Planning Group in the USDA.

2) Subsurface drainage appears to be a much less likely route of pesticide transport than surface runoff, and only a small proportion of pesticides applied to a field were found in tile drainage. The downward movement of pesticides in soil appears to be slight, though it will vary with several factors, including solubility and soil characteristics. The more soluble a pesticide, the faster it moves downward. Finer-textured soils have a greater adsorption capacity for pesticides, thus retaining them more than coarser-textured soils. A persistent pesticide, of course, might eventually reach ground water, whereas a less persistent pesticide would first dissipate by degradation or other processes. Thus, the highly soluble and persistent lindane in a sandy soil managed to reach underground water whereas DDT, parathion, and aldrin did not.

The soils of the San Joaquin Valley are valley soils, formed on alluvium from upland terraces. They include recent alluvial soils, shallow soils over hardpan, and basin soils. The eastern side of the valley has coarser-textured soils than the western side and hardpans are sometimes present. Saline and alkali soils are present in various parts of the valley. The general texture of the soils is loam, although the central part of the valley has mostly clay soils and two localized areas on the eastern side have wind-modified sandy soils.

These features of the soils of the valley generally discourage the downward movement of pesticides, although such movement is more likely in the localized and isolated wind-modified sandy soils. Generally speaking, contamination of ground water in the valley by pesticides is improbable. Considerably more pesticides remain in the soils of a field or decompose there than are removed by tile drainage or percolation to ground water.

3) Direct Application of pesticides to water involves their use to control aquatic weeds, rough fish, and aquatic insect pests. To minimize undesirable consequences, these activities are generally managed by professionals.

Nevertheless, direct application is considered to be one of the major pathways of pesticides into the aquatic environment, even though most herbicides registered for use in aquatic situations have restrictions requiring that the herbicide must dissipate at least partially before the water is again subject to normal use. Significant quantities of pesticides are used in the San Joaquin Valley by the Department of Water Resources and by the irrigation districts.

4) Atmospheric transport to the aquatic environment can result from drift at the time of application, from volatilization and codistillation from the terrestrial environment, and from wind erosion. Drift may be an important route of pesticide loss in the San Joaquin Valley but is probably more of a problem for adjacent land than for the water environment. High summer temperatures probably cause significant loss to the atmosphere of applied pesticides, through volatilization and codistillation, and such losses can travel great distances, adding to the difficulties of estimating how much returns to the water environment of the valley.

5) Other sources of pesticides in the water environment are industrial wastes, municipal wastes such as sewage effluents, agricultural wastes such as crop residues, food-industry wastes, and accidents and spills. A serious concern is the possibility of contaminating ground water with pesticides from used containers. Present regulations require that used pesticide containers be discarded at Class I dump sites (capable of handling hazardous material by being so situated that no drainage can later reach ground waters). There are presently only eleven Class I dump sites in the state of California, and none of them are in the San Joaquin Valley. As a result, large numbers of used pesticide containers (with significant amounts of concentrated pesticides) are piling up throughout the valley, periling the water supply and human health.

Degradation, Metabolism, and Persistence of Pesticides in the Aquatic Environment

When a pesticide is applied to soil or water, it is frequently transformed into other chemicals--biologically by soil and water organisms, nonbiologically by photolysis, or by chemical means. These transformations may increase or decrease the persistence, toxicity, and other properties of the material. Information on the degradation of pesticides in water is scant compared with that in soil, although many of the products found in soil might also be expected in water. The principal differences between the water and the environments that affect pesticide breakdown are the concentrations of the pesticide, adsorbate, or microorganisms.

Biological degradation of pesticides is by a number of pathways, principally hydrolysis, hydroxylation, dehalogenation, dehydrohalogenation, desulfuration (= oxidation), O-dealkylation, N-dealkylation, reduction, conjugation, and ring cleavage. Nonbiological degradation may be by the surfaces of mineral matter and organic matter in the soil, by hydrolysis, and by photolysis. The relative importance of these processes in a particular situation depends on many factors: microbial activity, physicochemical condition of the soil or water, etc. In addition, assumptions about importance in the field that are based upon laboratory experiments under controlled conditions should be made with circumspection.

The persistence of a pesticide in soil depends on many factors: the chemical structure of the pesticide, soil type, temperature, moisture, air movement, relative humidity, cover crops, microorganisms, application rate, mode of application, etc. The main processes by which these factors affect persistence are: decompositon by soil microorganisms, adsorption by soil colloids, leaching, chemical decomposition, volatilization and codistillation, adsorption by plants and other organisms, and soil cultivation.

Analysis of the literature on the persistence of pesticides in soils shows that, on average, chlorinated hydrocarbon insecticides have the longest persistence (several years), followed by some of the triazine herbicides (one or two years). Organophosphates and carbamates have low persistence. The soils of the San Joaquin Valley are loam soils, on average, with about 0.5% to 3% organic matter. These could be considered normal soils, and persistence data from the literature are probably applicable.

The limited information available on the persistence of pesticides in water indicates that some pesticides have a longer persistence in water than in soils, and some have a shorter. Pesticides in water have a high freedom of mixing and movement. When a pesticide is added or transported to water, most of it becomes adsorbed to sediments. Typically, the concentration in the water phase decreases rapidly and the concentration in the sediment or bottom mud increases for a period and then decreases slowly. After adsorption, a small fraction of the pesticide is gradually desorbed and released into the overlying water, where the pesticide concentration is maintained in dynamic equilibrium. Studies on major agricultural river basins of Califonria have indicated that an average pesticide concentration of 0.1 to 0.2 ppb in water may mean that bottom sediments contain 20 to 500 ppb. Generally, the persistence time is lower in water than in the sediments, and in some cases the sorbed pesticides are, for all practical purposes, removed permanently from the aquatic environment.

Impacts of Pesticide Pollution on the Aquatic Environment

The natural and man-made aquatic ecosystems of the San Joaquin Valley range in size from vernal ponds to impoundments such as the San Luis Reservoir, and from intermittent creeks to the San Joaquin River. The fish habitat exceeds 6,000 miles of streams and canals and 59,000 acres of lakes and reservoirs supporting both cold-water and warm-water species. The varied habitats are occupied by different species assemblages although the biological components of these environments have seldom been investigated.

Accurate prediction of the impact of pollutants on an aquatic system requires knowledge of: 1) the residual level of the pollutants; 2) the magnitude and duration of periodic high concentrations of pollutants; 3) the species found in a community; 4) the effect of the residual and periodic high levels of pollutants on individual species; 5) the magnitude of any synergistic effects that might occur when more than one pollutant is found in an environment; and 6) the effect on the community of altering the biology of an individual species.

An analysis of the literature on pesticides in the aquatic environment revelas that the bulk of availalbe information concerns the effects of insecticides or herbicides on a few invertebrate and fish species. Knowledge is limited on the effects of pesticides on primary producers and decomposers. There is very little work on protozoans or rotifers important groups of zooplankton and surprisingly little on annelids and molluscs even though these groups constitute the bulk of the benthic biomass in many environments.

Some groups of pesticides have also bben poorly investigated. Knowledge on pesticide effects decreases in the following order: insecticides and acaricides > herbicides > fungicides > nematicides and funigants. Increasing applications of these latter pesticides increases the need for studies of their effect on various aquatic biota.

Fish-kill data for the San Joaquin Valley for 1965-1969 indicate that fish kills attributed to pesticides have been relatively few compared with other

Table I Available Information on Effect of Organophosphorus Insecticides and Acaricides on Aquatic Species

Species	Parathion	Malathion	Phorate	Guthion	Methyl parathion	Ethion	Naled	Baytex	Delnav	Dylox	Dimethoate	Diazinon	Azodrin	Disyston	Carbophenothion	Phosphamidon	TEPP	Phosalone	Meta-Systox-R	Phosdrin	Systox
Primary producers																					
Phytoplankton	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Attached algae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Moss	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vascular plants																					
-submerged	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-emergent	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-floating	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Consumers																					
Zooplankton																					
-protozoa	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-rotifers	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-crustacea	x	x	-	x	x	x	x	x	-	x	x	x	-	-	x	x	-	-	-	-	-
Benthic invertebrates																					
-annelids	x	x	-	x	x	x	-		-	x	-	x	-	-	-	-	x	-	x	-	x
-insects	x	x	-	x	-	x	x	x	-	x	x	x	-	x	-	x	-	-	x	x	-
-crustacea	x	x	x	x	x	x	x	x	x	x	x	x	-	x	x	x	x	-	x	x	-
-mollusca	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-
Decomposers																					
Fungi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteria	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(x) Some information (laboratory or field) was obtained by our search procedure.

(-) No information was obtained.

causes. Also, loss of game fish has been less than the loss of non-game fish. Organochlorine pesticides have been the known or probable causes of fish kills in the valley, although the magnitude of this problem is decreasing with the declining use of these pesticides.

The concentrations of organochlorine compounds have been decreasing in the San Joaquin River, and residues found in various parts of the aquatic environment of the valley are significantly below the LC_{50} values to zooplankton, benthic invertebrates, and fish.

Much less information is available on the impact of organophosphorus insecticides on the aquatic environment of the valley. Although it is generally believed that these compounds are less persistent than the organochlorine pesticides and that they do not undergo biomagnification, the rapid increase in their use underscores the need for monitoring for these substances and research into their environmental impact. Table I shows available information on the effects of organophosphorus insecticides and acaricides on aquatic species.

More than four million pounds of herbicides were applied in the San Joaquin Valley in 1970. Such large applications could pose an environmental hazard, though little harm to the aquatic environment from the misuse of herbicides has been reported. One reason is that a permit must be obtained from the California Department of Fish and Game before pesticides are applied directly to water, and such a permit can be refused if there is danger of wildlife loss.

Herbicides are generally less toxic to aquatic fauna than are insecticides, and the values usually encountered in the aquatic environment are well below the toxic levels. Field observations indicate that herbicides applied to running water do not seem to be a hazard. In standing water, the concentrations necessary to control aquatic plants are not toxic to the fauna. Only with sodium arsenite is there severe toxicity from applications of the manufacturer's recommended dose.

Damage to the environment from herbicides is usually indirect. Thus, submerged vegetation frequently provides protection for fish species, so its elimination would make them more susceptible to predation. Also, eliminating this vegetation might alter the feeding habits of some species. A more general effect is that the concentration of dissolved oxygen is depressed by the decomposition of vegetation matter killed by herbicides.

In addition to insecticides and herbicides, millions of pounds of fungicides, nematicides, and rodenticides are applied annually in the San Joaquin Valley. The information available for assessing impact is even less for these types of pesticides than for inseticides and herbicides.

Four major conclusions can be reached from this review of available information on the impact of pesticides in the aquatic environment of the San Joaquin: 1) only limited information is available regarding the effects of pesticide use in the aquatic environment of the San Joaquin Valley; 2) both laboratory and field data regarding effects of pesticides on primary producers and decomposers in the aquatic environment are practically nonexistent, and information is only scant about effects on higher trophic levels; 3) presently available data are insufficient to provide assessment in greater depth of the impact of pesticides on the aquatic environment or to determine the extent to which damage might have been done to the environment; and 4) the limited evidence indicates that the agricultural use of pesticides in the San Joaquin Valley would seem to have had no significant adverse effects upon the aquatic environment.

Alternatives to Pesticides for Pest Control

While pesticides will continue to be used in the forseeable future, to protect crops and livestock from harmsul pests and to provide an adequate supply of high-quality food, feed, and fiber, these chemicals have had undesirable effects on the environment on some occasions. The need for change in pest management is obvious when one considers that: there are more insect pest species today than ever before; over 100 pest species of agricultural importance are resistant to pesticides; pest-control costs are increasing; and environmental pollution is of worldwide concern.

In some instances, alternative insecticides can be used in place of DDT and other persistent chlorinated hydrocarbons, though they often do not provide the same desired degree of control. Additionally, the use of these substitutes on major crops will often be much more costly. A variety of organophosphorus and carbamate insecticides are presently being substituted for the chlorinated hydrocarbons. Generalizing about these materials is very difficult, however, because of their differences in toxicity and use, and we lack extensive information about their possible side effects.

Physical techniques have been proposed for controlling insect pests and weeds. They include the use of sound, infrared radiation, visible light, ultraviolet light, ionizing radiation, cuticle abrasion, and flame cultivation. Except for ionizing radiation, these techniques have not been very successful in large-scale applications. They are either too costly or still in the experimental stage.

Chemical techniques presently employed for pest control include the use of hormones, chemosterilants, attractants and repellents, and antibiotics. Although 200 insect pheromones have been discovered, only the use of sex pheromones in combination with blacklight lamps have been encouraging (for control of tobacco hornwarm and the cabbage looper). Chemosterilants may be particularly useful to prevent the establishment of insect pests in new areas, as now employed against the pink bollworm in the San Joaquin Valley. These compounds must be thoroughly investigated, however, before they are released to the natural environment, since some chemosterilants are alkylating agents capable of producing mutagenic effects on some nontarget species. Many attractants have already been used to good advantage in detecting initial infestations of damaging pests and also in determining their spread into new areas. These chemical techniques, however, are applicable only to very small segments of the insect population.

Biological control, with numerous successes, has a potential probably that has not been fully exploited. It involves the use of parasites, predators, or pathogens on a host or prey population. It is an attractive alternative because natural enemies are very specific, do not contaminate the environment, and do not need to be reapplied annually. Once a biological control agent becomes established against a major pest, it provides permanent control of the pest. In the United States only 20 of 520 introduced species have provided significant control against a major pest. A single success, however, can provide substantial savings. It has been estimated that five major biological control programs produced savings in excess of $110 million in California during 1923-1959.

The use of pathogens as control agents is much more recent than the use of predators or parasites. There are over 300 known insect viruses which could be applied against specific insect species. Effective use of pathogens is currently limited to a few species, but further research may increase this number. These pathogens have very specific host requirements, and because of such specificity should provide less hazard than chemical insecticides. However, data will be required to establish the safety and effectiveness of an insect virus before it will be acceptable to regulatory agencies.

Mass release of laboratory-reared sterilized male insects has been responsible for extermination of the screwworm throughout the United States, but the technique is limited to pests which can be easily reared in the laboratory and occur in nature in relatively low population densities. Sophisticated breeding programs have been developed to produce pest-resistant plants, but it usually takes at least 10 years to develop acceptable resistant varieties.

Cultural methods have long been important in insect control. These methods include the destruction of plant parts left in the field after harvest, and early or delayed planting to avoid high populations of emerging insects. It has been suggested that only cultural control compares with biological control as a successful long-term means of pest management. Perhaps the outstanding example of cultural control involves Lygus bugs in cotton in California. Alfalfa is a preferred host of Lygus bugs, and interplanting alfalfa strips in cotton fields has proved a very effective control tactic in both experimental and commercial fields. A strip of alfalfa 16 to 32 feet wide is sufficient to keep Lygus bugs out of 300 to 400 feet of cotton. This technique is rather easy to employ and may receive wide application in the next few years.

Integrated control programs have received considerable attention in recent years. The technique involves not only a combination of chemical and biological control but also the use of all available practical and effective methods of insect control to bring maximum pressure on a destructive pest. There are some outstanding examples of successful integrated control programs, but such programs require extensive preliminary research and extended observation periods.

In the San Joaquin Valley, the most successful alternative to pesticides until recently has been various forms of biological control. Integrated control programs have recently been established for alfalfa, cotton, and grapes, and substantial progress has been made on programs in citrus, apples, walnuts, peaches, and woody ornamentals. Evaluating the success of alternative techniques is very difficult. Clearly, the use of these techniques has lowered the quantity of pesticides being released into the environment and has provided a more economical means of pest management.

Alternative techniques will be used more in the future, although a substantial increase will probably not occur soon. Contributing to increased interest in alternative techniques are economics and the deleterious environmental effects from pesticides. Many of these alternatives have only limited applicability and are yet to be refined. They will not be practical for field application for several years. Even techniques that can provide satisfactory pest control may not be employed by farmers until they become an economic necessity. In addition, alternative methods may achieve substantial acceptance only when they are as easy to employ as pesticides. It will also be necessary to provide information to the farmers as efficiently as is now done by pesticide manufacturers.

The nature of alternative techniques dictates that pest management will change significantly only if supported by governmental agencies. Substantial profits can be made from pesticide sales, but not from the sale of alternative techniques. Consequently, there is no incentive for private enterprise to develop alternatives. Developments of alternative methods of pest management will require financial support, time for research, and field testing. Utilization of available techniques is not primarily a scientific concern; rather, it requires economic, social, and political changes that may be difficult to bring about.

Laws and Regulations Governing Agricultural Pesticide Use in the San Joaquin Valley

Within the past seventy years, California has developed a regulatory system for pesticides control that is far more detailed than systems of most other states. Although the system is a product of state law and is administered in part directly by the State Department of Agriculture, major responsibilities for administration and enforcement are delegated to county agricultural commissioners. Chapter 8 of the report considers four matters pertaining to this regulatory system, particularly as it operates with regard to the sale and agricultural use of pesticides in the San Joaquin Valley: 1) the basic features, especially pesticides registration, permit control of the use of certain pesticides, and regulation of pest-control business; 2) some effects of this system in preventing environmental damage; 3) suggested changes that might increase environmental protection; and 4) important litigation related to the use of agricultural pesticides.

California law requires that pesticides be registered prior to sale, and that residue tolerances be established. The system is very similar to that federally required for products in interstate commerce. The number of California pesticide registrations has been declining recently, apparently as the result of a substantial increase in 1970 of the fee charged for each product registration. Use of a pesticide is unlawful if such use is in conflict with the registered label or with supplementary printed directions delivered with the pesticide, unless the use is expressly authorized by the Director of Agriculture or a county agricultural commissioner. Further use control of all pesticides is provided by specific limitations on drift, and by the need in some cases for a signed recommendation regarding the particular application. General rules keyed to the registration process thus provide some control over pesticide sales and use within the state. Use of the registration for purposes of environmental protection was emphasized by the legislature in 1969, when it provided that the Director of Agriculture is to "develop an orderly program for the continuous evaluation of all economic poisons actually registered" in order to "endeavor to eliminate from use in the state any economic poison which endangers the agricultural or non-agricultural environment, is not beneficial for the purposes for which it is sold, or is misrepresented."

Beyond these general restrictions, many pesticides in California are subject to a special set of use restrictions. Some forty-two chemical compounds are classified as "injurious materials" or "injurious herbicides," thus being subject to a special set of use restrictions and in most instances under permit control. The county agricultural commissioners administer the permit system. Variations are found among the eight San Joaquin Valley counties--for example, as to whether to use a "job" permit (each application requiring a permit) or a "seasonal" permit (blanket approval for one, many, or all of the listed materials for a season), or something inbetween; as to the nature of permit conditions to be imposed; and as to the role of the grower, as contrasted with that of the professional applicator.

Independently of general or special use restrictions on pesticides, there is in California considerable occupational regulation of those in one phase or another of the pest-control business. This regulation bears on professional applicators. The need for a state license and/or a county registration provides a means for administrative sanctioning of violations of use restrictions. Historically, it is the applicators or "pest control operators" who have been subject to regulation, and control has been tightest for air applicators. Regulation of those in other phases of the pest-control business, broadly defined, is very recent: only at the beginning of 1970 were requirements imposed for the state licensing of pesticide dealers and the county registration of "pest control agents" (generally, pesticide salesmen). Legislation approved late in 1971 requires that these agents, now to be called "pest control advisers," be licensed by the state, but this legislation contemplates full implementation of an examination and licensing system only by the beginning of 1974.

In addition to the Department of Agriculture, several other state agencies have authority that does or could significantly govern the sale and use of agricultural pesticides. Of primary significance for environmental protection is the authority of the State Water Resources Control Board and its regional affiliates, the State Department of Fish and Game, and the State Air Resources Board. Most of the eight San Joaquin Valley counties lie within the jurisdiction of the Central Valley Regional Water Quality Control Board, which in June 1971 promulgated an Interim Water Quality Management Plan. This includes some general and some specific references to pesticide levels as part of the plan's "water quality objectives," but within the region nothing has been done to establish specific waste discharge requirements for most agricultural waste waters--either for pesticide content or for other parameters. Action by the regional board has been taken, however, to deal with potential hazards to ground-water quality from the ground disposal of emptied pesticide containers. This major current problem is dealt with in some detail in Chapter 8. In addition to these efforts to protect water quality, the Department of Fish and Game has been active where degradation of water quality has been deleterious to fish, plant, or bird life. The State Air Resources Board, however, has given little attention to pesticide problems, which from a practical point of view are not now officially regarded as a hazardous air pollutant in California.

It is impossible at present to provide a complete assessment of the effects in preventing environmental damage resulting from California's present regulatory system for agricultural pesticides. The California Department of Agriculture has emphasized its use of the registration system to eliminate environmentally harmful materials--in particular DDT, DDD, and mercury. There is little evidence, however, that the Director of Agriculture has yet developed the "orderly program for the continuous evaluation of all economic poisons actually registered" that the legislature mandated in 1969. Attention seems to have been given to pesticides "in the limelight," and intensive review has thus been on a "problem" basis rather than the systematic and possibly problem-preventive basis anticipated by the legislature. As with registration, a review of successes claimed for the permit control system used for "injurious" materials and herbicides indicates that although this special system of controls has reduced or eliminated problems in several instances, it has been used too often only after a problem has become critical. Both "injurious" lists seem in fact to have "grown like Topsy," with no general criteria established that would allow systematic advance determination as to which pesticides should be subject to permit control and what kind of permit restrictions would be appropriate.

Two other general conclusions about California's permit control system seem justified. One is that major initiatives in the agriculturally important San Joaquin Valley have come from the state rather than from the various counties, despite the possibilities which do exist for county regulatory action. The other is that environmental considerations have been almost entirely lacking in using the permit system to bring more precise control of pesticide use. Typically, regulation has been undertaken because of pressure from a segment of the agricultural world aroused over damage to crops from pesticide applications. The only attempt in the San Joaquin Valley to use the permit control system for environmental purposes occurred in the late 1960's, when the insecticide Azodrin, widely used for the control of cotton pests, inflicted considerable damage on wildlife. Chapter 8 includes a detailed analysis of governmental reaction to this problem and of the failure of a system worked out on the assumption that a solution could be found through permit control tied to local consultation between the production-oriented officials of county departments of agriculture and the resource-oriented officials of the Department of Fish and Game. Evaluating the efficacy of permit control of pesticide use, whether for environmental or for other objectives, requires careful consideration of the administrative difficulties inherent in operation of such a system--particularly in a large county with intensive pesticide use. These difficulties are considered in Chapter 8, particularly noting recent changes in administration of the permit system in Fresno County.

In addition to considering the importance for environmental protection in the San Joaquin Valley of the pesticides registration system and the permit control system for "injurious" pesticides, Chapter 8 attempts to assess the significance of regulation of the pest-control business. Some entomologists in recent years have advocated a "prescription only" approach to agricultural pesticide use, and up to a point California is now moving in that direction. Paradoxically, until very recently regulation has been aimed at the person in a position like that of a "pharmacist"--the professional applicator--rather than at the person in the position of a "physician"--the recommender of the pesticide or, more broadly, the one who advises on what to do about a present or threatened pest problem in a given field. Even with the applicators, it is pointed out, the emphasis has been on air application, and the system used to sanction violations of the law has been inadequate.

Four changes are suggested regarding regulation of the sale and use of agricultural pesticides in California. These suggestions are based on twin assumptions: 1) that, no matter how much advance research is done, some types of environmental pollution cannot be precisely or perhaps even generally foreseen, so that from an environmental point of view the less pesticide used in agriculture the better; and 2) that, particularly given the existing apparatus for control of the pesticide inputs that may create pollution, progress in rationalizing and improving the system for controlling inputs is even more important than progress in direct regulation of agricultural wastes with some pesticide content. The four changes suggested in Chapter 8 are : 1) closer control over grower (nonprofessional) use of the "noninjurious" materials; 2) better enforcement where the law is violated by licensed and/or registered professionals in different phases of the pest-control business--with one possibility for improved enforcement being the development for "minor" violations of an intermediate sanction which would have more meaning than the present "slap on the wrist" notice of warning but would fall short of the rather drastic sanction of license or registration suspension or revocation; 3) consideration of reorganization of local responsibilities for environmental protection, on a rationale similar to that which led to formation of the Environmental Protection Agency within the federal government (the far greater difficulties of such action at the local level and the paramount need to preserve the present local field presence are, however, stressed); and 4) reform of the provision of pest-control advice to growers to ensure that pest-control advisers not only are technically competent (this would be hoped for from the state examination and licensing procedures to be implemented within the next two years) but are also entirely independent in making the judgment (which is as important as technical competence). True independence requires that, in judging how best to deal with a particular pest situation, all costs and benefits--social and environmental as well as individual, long-term as well as short-term--be adequately weighed. It is doubtful whether such independence in judgment can ever be achieved while most professional recommenders remain employees of chemical companies, yet this aspect of the problem is ignored in the current reforms providing closer regulation of those who provide pest-control advice to growers.

The final section of Chapter 8 briefly considers litigation related to the use of agricultural pesticides in the San Joaquin Valley. Little such litigation has taken place aside from crop-damage litigation, and the typical crop-damage suit does not raise important questions as to environmental protection. Mention is made of recent litigation in three areas: 1) the availability to the public of work reports filed with agricultural commissioners by professional applicators; 2) protection of the health and safety of farm workers; and 3) the use of compound 1080 in rodent control in Fresno County, which has given rise to what is apparently the first true "environmental" lawsuit over pesticide use in San Joaquin Valley legal history.

FOREWORD

As a part of the pesticide study authorized and required by Section 5(1) (2) of P.L. 91-224, the Environmental Protection Agency (EPA) has initiated a series of case studies of different uses of pesticides in the natural environment. Each study illustrates and documents the movement and impact of pesticides from the initial point of use, into the aquatic environment, and to the point of ultimate effect on the ecosystem.

The present study, WA 71-567, is confined to the effects of agricultural pesticides in the aquatic environment of the San Joaquin Valley of California. Using all available information, this report evaluates pesticide use on irrigated cropland and its impact on the valley's aquatic environment, in terms of the following subject areas, specified in the contract by the EPA:

A. Inventory of uses
B. Application techniques and types of pesticide materials being used
C. Route of pesticides into the water environment
D. Impact of pesticide pollution on the water environment
E. Degradation of pesticides and metabolites in the water environment
F. Alternatives used in area, and their degree of control
G. Regulations and laws governing the pesticides used

The study involved the following approaches:

1. Direct interviews.

   University scientists, officials of federal and state agencies, and county officials were interviewed to obtain their views on the subject areas of their expertise.
2. Literature survey and review.

The collection on pesticides in the Environmental Toxicology Library of the Food Protection and Toxicology Center is the finest in the Western States. Of particular importance to this study are specialized files developed since 1966:

a. Pesticide chemical information file. This file contains technical data from manufacturers and abstracts of articles selected on the basis of their relevance to residue analysis, metabolism toxicology, and pharmacology of pesticides, as well as the effects of these pollutants in the environment.

b. Pesticide and environmental pollution subject file. This file contains carefully selected reports, newspaper clippings, correspondence, and articles on the effects of pollutants on man's environment (air, water, soil, and food chains).

These two files formed the basis of our literature survey and review. To ensure that all information available from 1950 to 1971 was adequately covered, an examination was made of the following abstracting services:

Aquatic Biology Abstracts
Biological Abstracts
Chemical Abstracts
Pollution Abstracts
Selected Water Resources Abstracts
Soils and Fertilizers
Water Pollution Abstracts
Weed Abstracts

In addition, documents issued by federal, state, and local agencies, dissertations, and reports from industrial laboratories and universities were examined.

Awareness of pertinent current literature was maintained by scanning important primary journals as they arrived at libraries on the U.C. Davis campus. Also, computerized search services available from the Institute of Scientific Information were subscribed to for obtaining current titles on pesticides in the aquatic environment. Weekly printouts of pertinent literature were provided throughout the contracting period (July through November 1971).

The references cited at the end of each chapter represent only those publications that provide information pertinent to the subject coverage of the present case study. It should perhaps be emphasized that it is not the purpose of this report to list all available references on a given subject, since they are usually included in the review articles cited in each chapter. Our intent was to assess the current status of the pesticide problem in irrigated croplands with due respect to the past findings.

3. Selective retrieval of pesticide use information from data bank.

A data bank on pesticide use was established by the Department of Environmental Toxicology and the Agricultural Experiment Station of the University of California, in cooperation with the California Department of Agriculture. The information available, for use in both machine-readable form and hard copies, is of two kinds:

a. Fresno County--The raw data of this file, emanating from pesticide use reports in the County Agricultural Offices, cover the years 1968 and 1969. Each entry includes the following items: pesticide, crop, pest, data, location, amount of pesticide, mode of application, formulation, and area treated.

b. State of California--Becoming operational in January 1970, an elaborate data-collection system has been gathering information on pesticide use throughout the state. It makes current data available in machine-readable form on a continuing basis. Quarterly and annual cumulations are generated by computer and issued in printed form. Never before has such an up-to-date compilation been possible anywhere in the nation. It has proved to be an invaluable tool for research, teaching, and decision-making purposes.

The development of this unique data bank was supported, in part, by a National Science Foundation grand, GB-27398.

Chapter 8 of this report, Laws and Regulations Governing Agricultural Pesticide Use in the San Joaquin Valley, was prepared by Harrison C. Dunning, Acting Professor of Law at U.C. Davis. Professor Dunning specializes in environmental law and personally interviewed each of the eight county agricultural commissioners in the valley and selected members of their staff. Officials in several other state and county agencies were also interviewed in the course of preparation of this chapter.

CHAPTER 1

THE SAN JOAQUIN VALLEY

The San Joaquin Valley of California, the area selected for this case study, comprises the major portion of eight counties in the central and southern part of the state: San Joaquin, Stanislaus, Merced, Madera, Fresno, Kings, Tulare, and Kern. This 13,000-square-mile valley is surrounded by mountains on three sides: The Sierra Nevada on the east, the Tehachapis on the south, and the Coastal Ranges on the west. The north end of the valley, in San Joaquin County, meets the southern end of the Sacramento Valley, which is similarly surrounded by mountains on the east, north, and west. Thus, a large part of California's land mass is in the shape of an oblong bowl with a single huge central valley formed by the Sacramento Valley, in the north, and the San Joaquin Valley, in the middle and south.

The northern part of the central valley is drained by the Sacramento River and its tributaries, flowing generally southward. The natural drainage of the middle of the valley includes the San Joaquin River, flowing from east to west out of the Sierra and then north until it meets the Sacramento in a large delta west of Stockton. From the delta, the waters of the Sacramento and the San Joaquin flow in a westerly direction to the sea, through Suisun Bay and the Golden Gate. This break in the coastal mountains between San Francisco and Marin Counties provides the only sea-level route into and out of the central valley. A low east-west ridge divides the San Joaquin Valley in half, and the southern portion (referred to as the Tulare Basin) has no natural drainage outlet. Figure 1.1 shows the land forms of California.

The primary natural source of water in the central valley is precipitation from moisture-laden air from the Pacific Ocean. The western slopes of the coastal ranges remove most of the water from the lower air masses, resulting

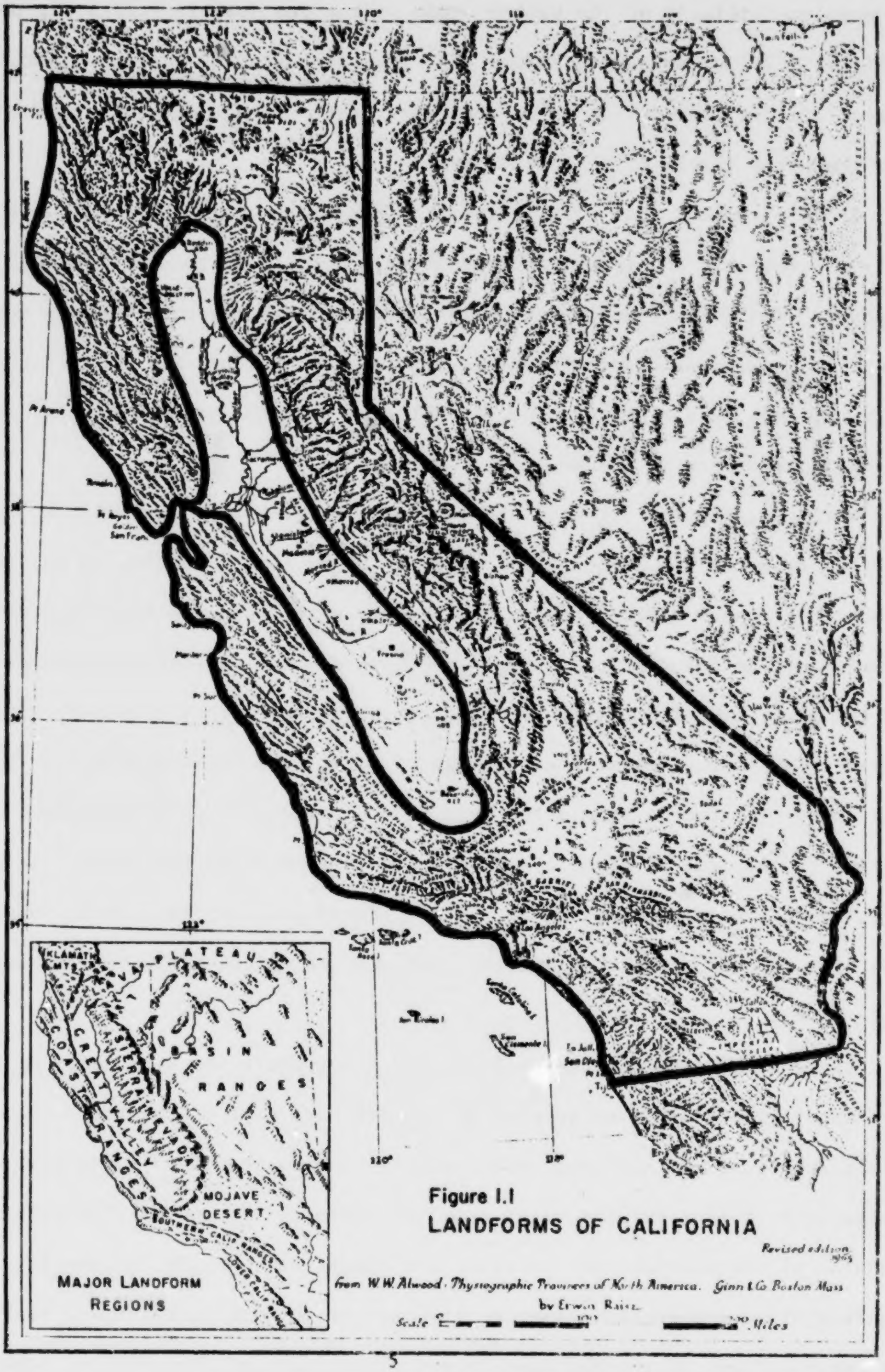

120°
118°
Pt Arena
San Fran.
Fresno
Los Angeles
San Diego
KLAMATH MTS.
LAVA PLATEAU
BASIN RANGES
SIERRA NEVADA
GREAT VALLEY
COAST RANGES
MOJAVE DESERT
SOUTHERN CALIF. RANGES
MAJOR LANDFORM REGIONS

Figure I.1
LANDFORMS OF CALIFORNIA

Revised edition 1965

from W. W. Atwood · Physiographic Provinces of North America. Ginn & Co Boston Mass
by Erwin Raisz

Scale 0 100 200 Miles

in very low rainfalls on the western side of the San Joaquin Valley, as shown in Figure 1.2 (Durrenberger, 1970). The higher mountains in the northern and eastern rims of the central valley, however, extract huge quantities of water from the upper levels of the atmosphere.

It is estimated that each Californian requires almost 200 gallons of water daily for domestic and industrial purposes, and 1,300 gallons for agricultural purposes. The water-supply problem in the central valley and in the state is not one of insufficiency but of maldistribution: most of the rainfall and runoff are in the north and east, while most of the population, industry, and agriculture are in the south and west.

Early attempts to irrigate the San Joaquin Valley depended on the diversion of water from the San Joaquin River and its tributaries, arising in the Sierra Nevada on the east side. The quality of this water was excellent, but the quantity proved insufficient to meet the demands of a burgeoning population and the agricultural potential of the region. Farmers then turned to pumping ground water to supplement the shortage of water from surface sources. By 1930, more than two million acres were under irrigation, and the valley had reached the irrigation capacity of this system of streams and wells. In addition, the growing practice of pumping groundwater for irrigation purposes gave rise to drainage and salination problems, as discussed by Pafford and Price (1969).

By contrast, the Sacramento River and its tributaries were carrying far more water than could ever be used in the northern part of the state. In the 1930's the State of California and the U.S. Government joined to develop a system to carry the surplus water from the north to the south. The principal features of the initial plan provided for Shasta Dam, on the Sacramento, to regulate flows and generate electricity, and Friant Dam to catch and store the natural flows of the San Joaquin and divert most of it north and south

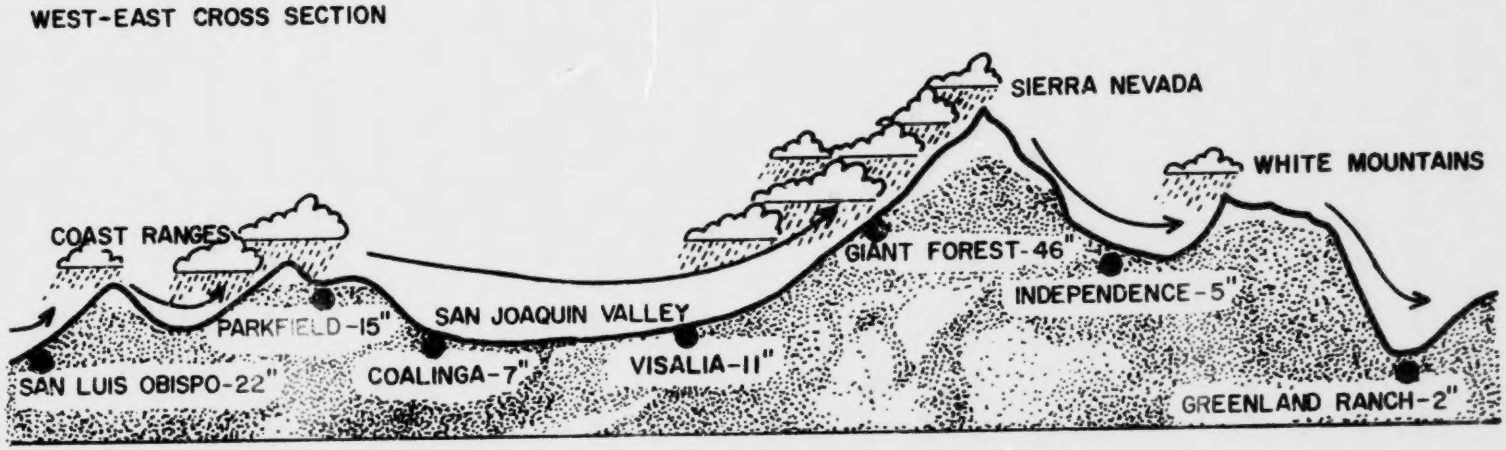

WEST-EAST CROSS SECTION
COAST RANGES
SAN LUIS OBISPO-22"
PARKFIELD-15"
COALINGA-7"
SAN JOAQUIN VALLEY
VISALIA-11"
GIANT FOREST-46"
SIERRA NEVADA
INDEPENDENCE-5"
WHITE MOUNTAINS
GREENLAND RANCH-2"

Figure 1.2 Rainfall along East-West Profile of California
(Durrenberger, 1965)

along the east side of the valley. Irrigation water for the west side of the valley was to be obtained by pumping water from the Sacramento-San Joaquin Delta into the north end of a canal which would run for 117 miles, emptying into a pool at Mendota. From the Mendota pool, this water would flow back to the delta in the San Joaquin stream bed. The initial project has been supplemented over the years by the construction of many other dams, canals, power plants, etc., as shown in Figure 1.3.

The most ambitious supplement to the initial plan is the combination of the California Aqueduct and the San Luis Canal. The latter is a federal project. The northern portion of the California Aqueduct is west of and roughly parallel to the Delta-Mendota Canal, carrying water from the delta to O'Neill Forebay. From the forebay, water is pumped into the San Luis Reservoir for storage, and irrigation water is provided in the San Luis service area of the west side of Fresno and Kings Counties. At Kettleman City, water from the south end of the San Luis Canal flows into the southern portion of the California Aqueduct, providing water for the west side of Kern County, at the south end of the San Joaquin Valley, and for pumping over the Tehachapis into the Los Angeles Basin.

As this segment of the California Water Project nears completion, it is evoking strong reactions from a number of sources: from those who think that large agricultural landholders on the south and west side of the valley are getting disproportionate benefits; from those who think that the availability of additional water in Los Angeles will compound population growth and congestion in that area; from those who think that the diversion of additional large quantities of water from the delta will upset the ecology of that unique area and degrade the quality of water flowing from the delta into Suisun, San Pablo, and San Francisco bays.

For many years there has been concern about the effect of large-scale irrigation on the water table in the San Joaquin Valley and on the quality of proceed with the section of drain that would connect Kesterson Reservoir with the Delta.

With all of these developments, California has approximately one-quarter of all the irrigated land in the United States, and irrigation of these 8 million acres accounts for more than 85 percent of the water used in California. Irrigation districts hold an important place in the history of water development in California. Many develop and distribute water for agricultural consumption, while others provide solely domestic and industrial service. The 250 members of the Irrigation Districts Association handle about two-thirds of all the water developed in the State and distributed for any purpose.

Land use projections for 1975 anticipate that the San Joaquin Valley will contain over half of the state's irrigated cropland and about half of the state's total cropland.

The principal reason for this irrigation system is the intense agricultural production of the state and the valley. California, with a gross of $4,640,000,000 from agriculture, has for 22 consecutive years been rated the number one farming state in the nation. The state commercially produces about 250 crop and livestock commodities, aside from nursery crops. With less than 3% of the nation's farms, California produces 25% of the nation's table foods, 43% of the nation's vegetables, and 42% of the nation's fruits and nuts. It also accounts for 20% of the nation's fiber production. Of the eight counties in the valley, six were in the top ten counties of the United States in value of farm production according to the 1964 U.S. Census of Agriculture. Three of these counties--Fresno, Tulare and Kern--led all U.S. counties.

Irrigation has, indeed, increased the acreage of cultivated land and has contributed to increased yields on previously cultivated land. The San Joaquin receiving waters. These problems were reviewed at the Seventh Congress of the International Commission on Irrigation and Drainage (Pafford and Price, 1969):

> As long as irrigation development in the San Joaquin Valley was limited to east side areas using the good quality water from the east side tributaries, there were relatively few areas of either high water tables or poor water quality. There were very low concentrations of salts in the water and such salts as were present moved easily down through the permeable soils and into the deep ground-water aquifers and thence to the valley center. A small problem did develop on the west side near Los Banos where water of the San Joaquin River was diverted on to the older, tighter basin soils. The problem was chiefly one of high water tables near the valley trough, however, and was solved by providing drainage outlets to the San Joaquin River.
>
> When deep-well pumping reached major proportions, west side drainage problems became more severe because of a combination of factors unique to the west side. The west side soils are tighter than those of the east side; the west side soils contain nearly impervious strata; and the ground water is appreciably more salt laden than the waters of the east side surface streams. The importation of up to 1,541 million m^3 (1,250,000 acre-feet) per year from the Sacramento Valley again increased the total water application, the amount of land under irrigation, and the total salt application. The increase in salts resulted from the fact that in transiting the Sacramento-San Joaquin Delta, the supply from the Sacramento River picked up local Delta agricultural return flows and return flows carried into the Delta by the San Joaquin River.

In 1967, the Federal Water Pollution Control Administration published a study (U.S. Federal Water Pollution Control Administration, 1967) regarding the probable effects of the state's proposed San Joaquin Master Drain on the quality of waters in the Sacramento-San Joaquin Delta and San Francisco Bay. The report assessed the effects of drainage waters on the total dissolved solids, total nitrogen, biological oxygen demand, dissolved oxygen, and temperature of the receiving waters. The report also concluded that the concentration of pesticides in the effluent from a master drain would be approximately the same as in the receiving waters of the Delta and the Bay.

In spite of the desirability of a San Joaquin Master Drain, the state portion of the project has been postponed indefinitely. However, a drain for the San Luis service area is nearing completion, and the drain discharges will be impounded in a reservoir at Kesterson. There is no present schedule to

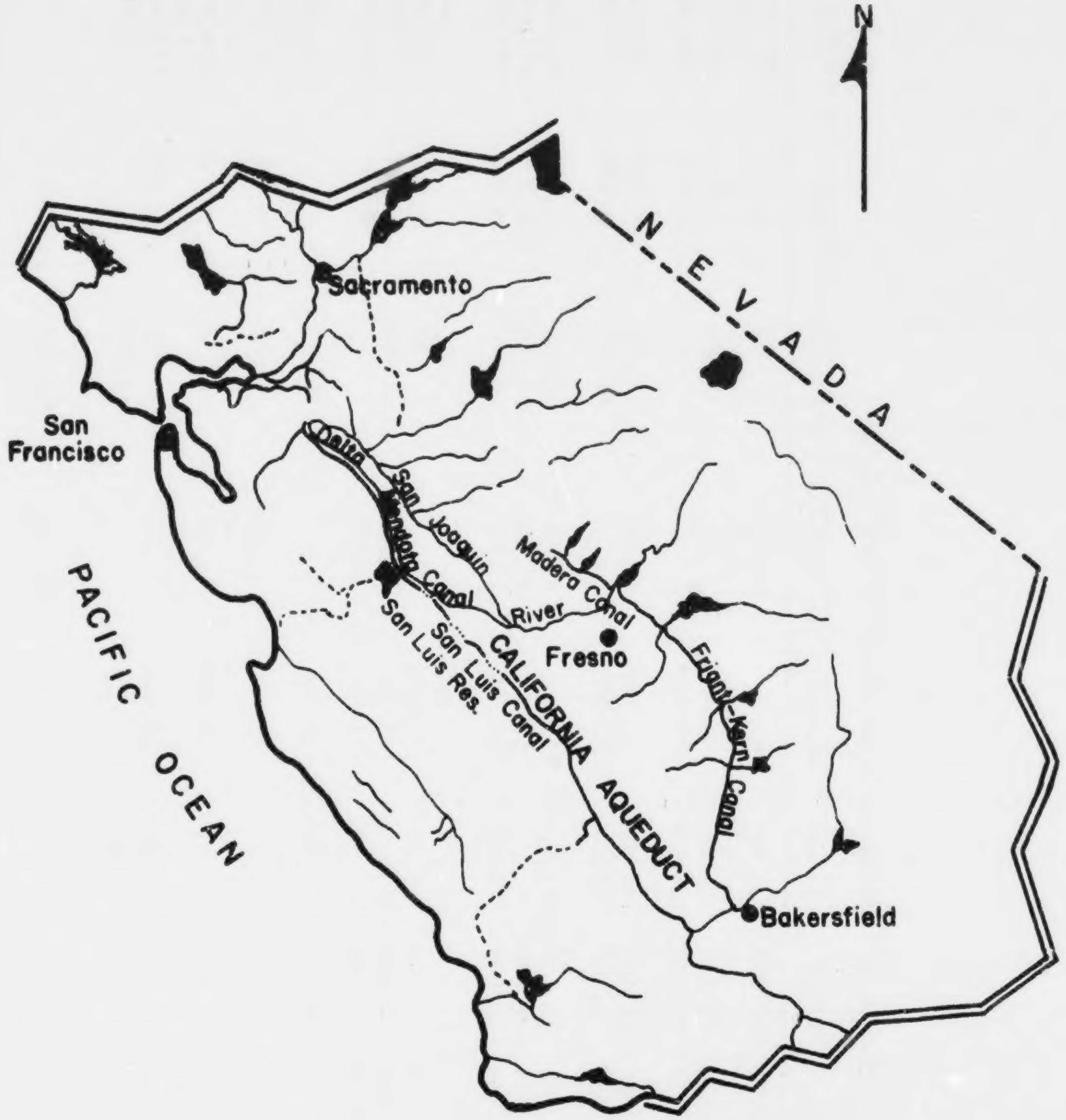

N
NEVADA
Sacramento
San Francisco
PACIFIC OCEAN
Delta
San Joaquin River
Delta Mendota Canal
Madera Canal
Fresno
San Luis Res.
San Luis Canal
CALIFORNIA AQUEDUCT
Friant-Kern Canal
Bakersfield

Figure 1.3 Water Distribution System, Central California (Source: California Department of Water Resources Bulletin No. 160—70, 1970)

Table 1.1 Harvested Acres of Field Crops (1970)

Crop	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	Total
Barley	195,000	100,000	110,000	31,600	49,700	58,000	26,000	75,400	924,700
Beans	11,858			3,900	2,950	16,120	32,420	7,000	74,248
Corn	21,500	3,000	22,000	11,600	20,700	33,000	3,000	11,500	126,300
Cotton	167,000	171,000	93,000	36,800	23,500			118,400	609,700
Hay									
Alfalfa	150,000	124,000	66,000	48,500	73,530	61,800	41,300	100,000	665,130
Grain	2,000	9,860	2,500	2,200	22,375	13,800	19,750	4,100	76,585
Pasture									
Irrigated	85,000	20,000	18,000	45,600	125,500	85,850	82,000	22,400	484,350
Range	1,300,000	2,612,000	300,000		789,000	141,400	400,000	900,000	6,442,400
Other	129,000	116,000	70,000	502,000	3,525	112,900	2,060	5,000	940,485
Peanuts									
Peas					540				540
Oats	2,500			1,700	1,530	3,220	690	3,500	13,140
Rice	19,000	1,900	1,100	1,250	6,200	7,050	1,960	545	39,005
Safflower	80,000	8,940	25,000	280	2,100	4,420		1,190	121,930
Silage									
Corn	10,000		8,000	3,800	19,200		30,000		71,000
Other	3,500		3,000						6,500
Sorghum	19,000	43,000	20,000	5,000	16,350	36,000	8,000	30,000	177,350
Straw						2,100			2,100
Sugar Beets	37,040	36,600	11,450	1,520	10,378	25,400	4,180	12,310	139,878
Sunflower						3,821			3,821
Wheat	45,000	48,000	37,000	6,000	11,844	8,580	700	11,000	168,124
Misc.			145				1,200		1,345
Total									
1970	2,148,398	3,312,368	787,215	701,750	1,174,593	630,401	653,260	1,329,245	
1969	2,185,197	3,322,733	785,402		1,090,232	622,260	655,270		

Table 1.2 Harvested Acres of Fruit and Nut Crops (1970)

Crop	Fresno	Kern	Kings	Madera[1]	Merced	San Joaquin	Stanlislaus[1]	Tulare[1]	Total
Almonds	6,416	1,749	394	10,545	21,864	20,012	29,695	3,578	94,253
Apples		177		52				183	412
Apricots	472		362	62	1,289	3,223	9,578	248	15,234
Avocados				4				237	241
Bushberries	130				33		323		486
Cherries				18	58	8,085	211	57	8,429
Citrus	273				29				302
Grapefruit								148	148
Lemons	128			52			78	3,433	3,691
Limes							1	5	6
Oranges				3,310			65		3,375
Navels	9,660	4,839						57,246	71,745
Valencias	2,379	2,035						25,098	29,512
Tangerines		318					63	1,210	1,591
Figs	10,849			2,865	2,525		15	161	16,415
Grapes									
Raisin	148,737	21,143	2,807	28,240	5,497		5,997	34,485	246,906
Table	9,524	10,611		511	201	21,708	129	27,125	69,809
Wine	12,856	6,495	654	8,577	7,534	22,111	14,075	7,731	80,033
Nectarines	4,321	186	104	185	229	42	224	3,888	9,179
Olives	885	210		785	134	197	217	14,263	16,691
Peaches									
Clingstone	1,973	2,123	1,303	1,401	7,716	6,659	25,093	3,520	49,738
Freestone	7,669		624	1,257	2,899	1,165	3,616	2,971	20,201
Pears		301		1		1,046	553	109	2,010
Pecans				17			13		30
Persimmons	59			18			3	245	325
Pistachio Nuts				2,314			8	305	2,627
Plums	6,922	1,626	251	430	104	492	96	9,430	19,351
Pomegranites	372	94		2			3	932	1,404
Prunes					957		112	4,033	5,102
Quince								76	76
Strawberries	230				3	74	68		375
Walnuts	3,001		2,570	1,133	7,206	21,600	24,109	23,544	83,163
Misc.	684	72	501		40		851		2,076
Non-bearing Acreage	?	44,826	?		15,643	15,025			75,494
Total 1970	227,540	51,976	9,570	61,779	58,407	106,431	83,865	137,321	
1969	223,299	51,099	9,064		54,796	102,421			

1. Includes non-bearing acreage as well as harvested acres.

Table 1.3 Harvested Acres of Vegetable Crops (1970)

Crop	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	Total
Asparagus						26,245		317	26,512
Beans	350	553			2,630	1,680	8,910	1,857	15,980
Beets						100			100
Broccoli							720		720
Cabbage	120					18	435		573
Carrots		4,590				770			5,360
Cauliflower						400	815		1,215
Chinese Veg.	275								275
Corn	160	914			736	125	20	12	1,967
Cucumber	300					1,500		310	2,110
Egg Plant								67	67
Garlic		614		220				170	1,004
Lettuce	5,733	3,010				440			9,183
Melons									
Cantaloupe	25,000	4,190	1,750		5,880	63	900		37,783
Casaba	100					495		35	630
Cranshaw	350					230			580
Honeydew	410					291	2,590	745	4,036
Persian	40						150	30	220
Watermelon	400	3,510		30	700	1,530	1,020	448	7,638
Other		787	50		1,110		853		2,800
Onions	950	6,420				2,070	1,230	110	10,780
Peas		159			500	4,535	3,640	66	8,900
Peppers	650	318			292	880	990	348	3,478
Potatoes		39,680	590	1,500		1,865		615	44,260
Pumpkins						962	400		1,362
Radishes	750								750
Spinach							2,060		2,060
Squash	325					435	60	148	968
Sweet Potatoes	680	105		10	3,870	120	330		5,115
Tomatoes	12,240	2,555	932	750	9,798	32,500	9,090	1,248	69,113
Turnips	25								25
Misc.	3,325	1,280	576		585	2,650	4,080		12,496
Total									
1970	52,183	68,856	3,898	2,510	26,500	76,904	38,293	6,526	
1969	54,435	72,440	4,660	3,195	31,737	86,309	39,800		

Table 1.4 Harvested Acres of Seed Crops (1970)

Crop	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	Total
Alfalfa	60,686	11,367	4,606	800	100	85	1,877		79,521
Barley	5,243		5,487					404	11,134
Beans				300	1,957	6,940		11	9,208
Cabbage				60					60
Canteloupe					93				93
Carrot				135					135
Clover				140		1,272	460		1,872
Cotton	8,105								8,105
Cowpeas		861							861
Grain		1,160				6,470			7,630
Oats								19	19
Wheat			400					125	525
Lettuce				75					75
Onion				230					230
Ornamental						385			385
Potatoes						960			960
Squash					58				58
Vegetable	3,102	173				160			3,435
Misc.	46,182	376	1,352	80	110		1,720		49,820
Total									
1970	123,318	13,937	11,845	1,800	2,318	14,272	4,057	559	
1969	63,196		9,685	2,300	4,322	16,067	3,199		

and livestock has risen steadily. The principal uses of cropland in the valley in 1970 were as follows:

	acres
Pasture and range	7,867,235
Field crops	2,870,065
Fruit and nut crops	812,670
Vegetable crops	275,670
Seed crops	172,106

Except for pasture and range, the breakdown by crop and by county for each of the remaining four categories can be seen in Tables 1.1, 1.2, 1.3, and 1.4, which were obtained from the county agricultural commissions' annual report.

To maintain the high quality of their agricultural products, and a high level of productivity in the valley, the farmers there depend heavily on pesticides to combat diseases, insects, and weeds. According to a recent report of the U. S. Department of Agriculture, the use of pesticides has accounted for 10-15% of the increase in farm output in the nation since 1940, and also is responsible for $2-2.5 billion of the annual saving in production resources. It has been estimated that approximately 20% of all pesticides sold in the United States are sold in California, and 50% of the pesticides used in California are applied in the San Joaquin Valley.

References, Chapter 1

Durrenberger, R. W. 1965. Patterns on the land. Palo Alto, California, National Press Books.

Pafford, R. J. and E. P. Price. 1969. A disposal system for agricultural waste waters in the San Joaquin Valley of California. Transaction of the Seventh Congress of the International Commission on Irrigation and Drainage, Mexico City, 1969. (R. 30, Question 26).

U. S. Federal Water Pollution Control Administration. South West Region. Central Pacific Basin Project. 1967. Effects of the San Joaquin Master Drain on water quality of the San Francisco Bay and Delta. San Francisco, U. S. Dept. of the Interior, Federal Water Pollution Control Administration.

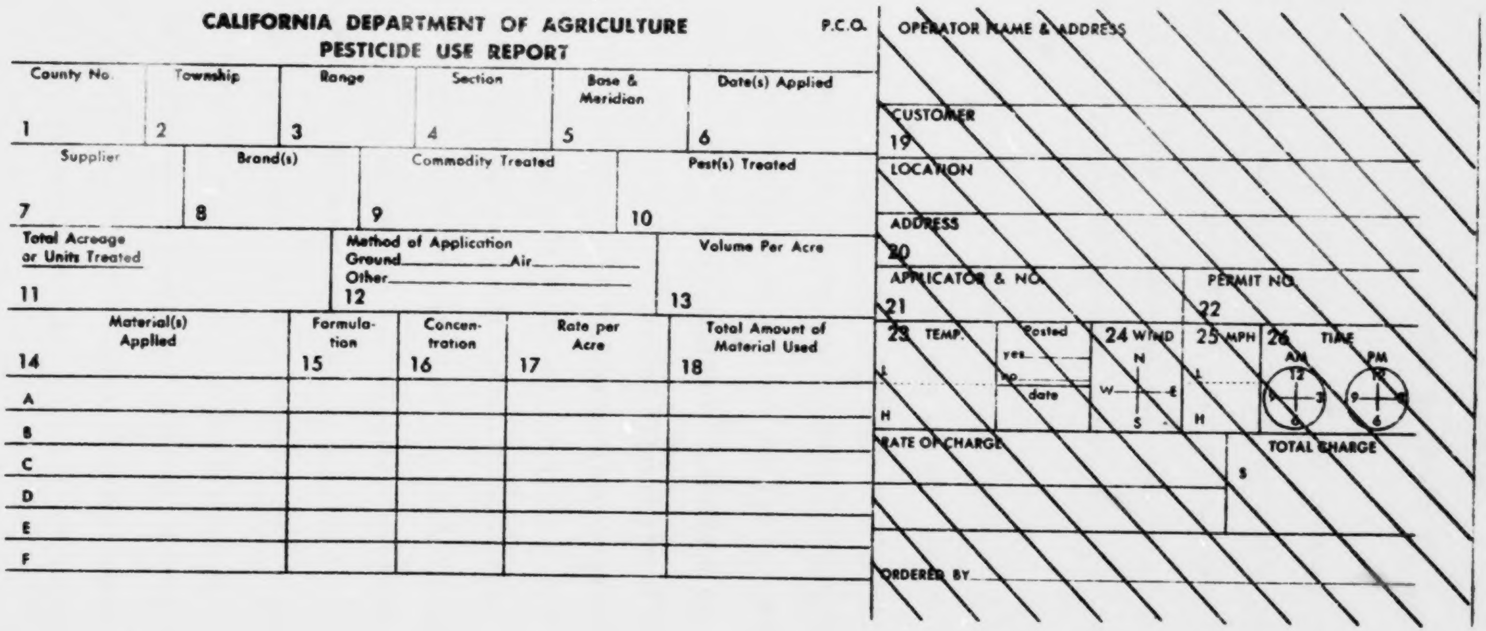
CHAPTER 2

INVENTORY OF USES

Recognizing the inaccessibility of data on pesticide use, the University of California Agricultural Experiment Station, in 1969, initiated "A Study of Chemicals Released in the San Joaquin Valley." Fresno County was selected for a pilot effort because it is not only the top county in agricultural production in the United States, but also the biggest consumer of pesticides among the counties of California.

Under the aegis of this study, a data bank on pesticide use was developed from information contained in pesticide use reports filed in the Fresno County Agricultural Commissioner's Office in 1968. These reports are required for all pesticides used by licensed agricultural pest-control operators and for all grower-applied pesticides that are on the list of injurious materials. A particular pesticide applied by the grower that was not on the list of injurious materials is not necessarily recorded in the data bank. This portion of our data bank includes 43,149 records of agricultural pesticide use in 1968 in Fresno County.

In collaboration with this study, the California Department of Agriculture developed an elaborate system for collecting and processing the same type of information on pesticide use on a current basis for the entire state, starting in January 1970. The report form for agricultural use of pesticides is shown in Figure 2.1. The unshaded portion is the copy forwarded to the California Department of Agriculture. When these reports were received in Sacramento, the following data were encoded and punched onto cards: the chemical; commodity or crop; pest (up to a maximum of 3); location (county, township, range, and section); date of application; acreage; mode of application (aerial, ground, or other); formulation type; concentration of active ingredient (in percent or in pounds



CALIFORNIA DEPARTMENT OF AGRICULTURE
PESTICIDE USE REPORT
P.C.O.

County No. 1	Township 2	Range 3	Section 4	Base & Meridian 5	Date(s) Applied 6

Supplier 7	Brand(s) 8	Commodity Treated 9	Pest(s) Treated 10

Total Acreage or Units Treated 11	Method of Application Ground______ Air______ Other______ 12	Volume Per Acre 13

Material(s) Applied 14	Formulation 15	Concentration 16	Rate per Acre 17	Total Amount of Material Used 18
A				
B				
C				
D				
E				
F				

OPERATOR NAME & ADDRESS

CUSTOMER
19

LOCATION

ADDRESS
20

APPLICATOR & NO.
21

PERMIT NO.
22

23 TEMP. L H	Posted yes____ no____ date	24 WIND N W E S	25 MPH L H	26 TIME AM 12 9 3 6 PM 12 9 3 6

RATE OF CHARGE

TOTAL CHARGE
$

ORDERED BY__________

Figure 2.1 Pesticide Use Report

per gallon); and the rate of application per acre. Each record was then subjected to various verification procedures, and when a record showed an unregistered use, a report was sent to the county agricultural commissioner for appropriate action, such as sampling the treated area for residue analysis.

In addition to the reports on agricultural uses of pesticides, the 1970 files include records on pesticide use for residential and structural pest control, insect vector control, and uses by governmental agencies. Monthly and quarterly summary reports are published by the state (California Dept. of Agriculture, 1971). When the records for 1970 were completed, the entire file of the state's data, comprising 677,662 records, was entered into our data bank. For the present case study, the records for the eight counties of the San Joaquin Valley were extracted from the file and subjected to various verification routines.

This initial search yielded 207,140 records. Of these 29,363 were found to be artifacts entered into the file by the state to facilitate the generation of its various reports and summaries. For example, each agricultural record contains space for three target pests. However, for certain data manipulations, it was convenient for the Department of Agriculture to enter duplicate records into the file when there was more than one target. These duplicate records were readily identifiable, and had to be taken into consideration in certain summaries, but they did not represent records of separate pesticide use. Of the remaining 177,777 records, 69 (.04%) were eliminated by our verification procedures, for reasons as follows: unreasonable dose rates, as explained below (54); internal inconsistency between dose rate and total amount applied (6); application in 1971 (7); erroneous chemical code (2).

On the basis of type of user (and consequently, the source of the report) the 177,708 records in the 1970 San Joaquin Valley file can be broken down into four groups, as shown in Table 2.1. Agriculture accounted for 88% of the records in the San Joaquin Valley file, and accounted for 91% by weight of

Table 2.1 Some Substances Used in the San Joaquin Valley, 1970, by User

Substance	Agricultural		Vector Control		Structural and Residential		Government Agencies		Total	
	Records	Pounds	Records	Pounds	Records	Pounds	Records	Pounds	Records	Pounds
PETROLEUM SOLVENTS	6579	21794690.2	559	1501900.4	105	319084.0	171	3854894.0	7414	27670568.7
MERCURY TREATED SE	1895	20573802.1	0	0.0	0	0.0	0	0.0	1895	20573802.1
SULFUR	10361	9130711.8	0	0.0	2	49.2	31	1795.5	10394	9132556.5
CALCIUM HYDROXIDE	1653	3571444.8	0	0.0	4	1850.0	0	0.0	1657	3573294.8
SODIUM CHLORATE	6405	2492692.8	1	24.0	20	4844.0	18	19961.4	6444	2517522.2
DORMANT OILS	1171	1811340.1	0	0.0	34	5830.3	10	222396.0	1215	2039566.4
TOXAPHENE	3164	1765741.9	0	0.0	0	0.0	2	420.0	3166	1766161.9
UREA	2036	1486983.6	0	0.0	2	63.0	0	0.0	2038	1487046.6
DDT	3652	869789.5	11	15.6	421	4099.4	2	210.0	4086	874114.5
TELONE	245	820492.8	0	0.0	0	0.0	0	0.0	245	820492.8
D-D MIXTURE	225	755731.3	0	0.0	0	0.0	0	0.0	225	755731.3
MALATHION	2903	289592.0	202	8505.3	708	19484.7	56	336686.0	3869	654268.0
PARATHION	10835	389901.1	391	31093.1	5	11.5	1	40.0	11232	421045.7
KELTHANE	5198	510841.1	0	0.0	29	35.5	5	51.5	5232	510928.1
SPREADERS	6730	476549.5	80	935.7	52	1722.3	53	4620.5	6915	483828.0
ZINC	3295	467418.1	0	0.0	7	71.9	3	7.8	3305	467497.8
METHYL BROMIDE	221	421948.5	0	0.0	61	19803.2	4	135.7	286	441887.4
CU SULFA-PENTAHYDR	1677	393493.8	0	0.0	23	853.4	17	18067.0	1717	412414.2
ZINC SULFATE	1810	365279.7	0	0.0	19	219.8	0	0.0	1829	365499.5
2,4-D	3612	303252.9	1	[illegible]	87	20985.8	106	11874.0	3806	336131.6
CARBARYL	2843	326134.7	0	0.0	241	803.6	11	52.2	3095	326990.5
OIL OF VITRIOL	79	324381.0	0	0.0	0	0.0	0	0.0	79	324381.0
COPPER	1545	279047.2	0	0.0	13	216.7	1	106.0	1559	279369.9
PHORATE	3368	268128.8	0	0.0	3	1408.7	5	26.0	3376	269563.5
CHLOROPICRIN	189	251611.3	0	0.0	7	2.0	2	10.2	198	251623.5
GUTHION	6555	248408.0	0	0.0	6	14.5	3	15.8	6564	248438.3
DEF-DEFOLIANT	1631	242820.7	0	0.0	1	0.0	0	0.0	1632	242820.7
MANEB	1449	242068.8	0	0.0	7	24.0	0	0.0	1456	242092.8
METHYL PARATHION	3545	222541.5	262	13928.9	0	0.0	5	187.8	3812	236658.2
TRIFLURALIN	2160	217393.1	0	0.0	0	0.0	1	16.0	2161	217409.1
DBCP	374	201192.4	0	0.0	0	0.0	0	0.0	374	201192.4
ENDOSULFAN	2686	191703.5	0	0.0	19	38.7	1	1.0	2706	191743.2
ETHION	3022	188947.3	0	0.0	1	32.6	0	0.0	3023	188979.9
NALED	4110	184637.1	4	50.0	35	883.4	2	24.0	4151	185594.5
HYDRATED LIME	86	176598.4	0	0.0	0	0.0	0	0.0	86	176598.4
BAYTEX	35	758.0	1173	165613.2	19	18.9	0	0.0	1227	166390.1
XYLENE	8	802.3	4	1009.2	0	0.0	4	148062.5	16	149874.0
DELNAV	1614	145298.5	0	0.0	19	15.8	4	138.2	1637	145452.5
SINOX	1113	140999.3	1	55.0	8	2794.1	13	1523.2	1135	145371.6
CAPTAN	773	130989.2	0	0.0	9	265.0	0	0.0	782	131254.2
DYLOX	1066	127274.4	0	0.0	0	0.0	0	0.0	1066	127274.4
DIMETHOATE	3615	110371.0	0	0.0	7	40.5	8	72.7	3630	110484.2
DIAZINON	1913	99070.1	1	4.0	3173	6141.5	23	124.4	5110	105340.0
ANSAR 170	361	37399.3	5	132.2	90	5081.1	176	60937.4	632	103550.0
SIMAZINE	1316	69700.8	5	210.5	226	6143.2	95	26203.6	1642	102257.9
DALAPON	391	75311.8	15	615.4	85	6538.5	119	19302.8	610	101848.5
CU SULFATE BASIC	310	93380.7	0	0.0	4	5842.8	1	1752.4	315	100975.9
AZODRIN	1048	96529.1	0	0.0	0	0.0	1	40.0	1049	96569.1
SODIUM ARSENITE	909	91061.8	0	0.0	15	2975.5	0	0.0	924	94037.3
Chlordane	77	5229.4	0	0.0	3557	78711.9	12	46.5	3646	83987.8
DISYSTON	1290	83340.6	0	0.0	0	0.0	0	0.0	1290	83340.6
DNBP	485	75379.8	2	13.2	14	7508.8	1	198.0	502	83099.8
PARAQUAT	3063	66788.6	3	2.7	101	1573.7	118	11267.0	3285	79632.0
ANSAR 138	65	4897.8	1	12.4	113	28116.1	128	44591.2	307	77617.5
PROPANIL	183	75833.9	0	0.0	0	0.0	0	0.0	183	75833.9
SUGAR	273	72283.9	0	0.0	0	0.0	0	0.0	273	72283.9
OMITE	1602	72233.5	0	0.0	0	0.0	0	0.0	1602	72233.5
MAGNESIUM CHLORATE	106	70704.0	0	0.0	0	0.0	0	0.0	106	70704.0
DACTHAL	162	69900.6	0	0.0	4	36.1	3	100.9	169	70037.6
CARBOPHENOTHION	2367	69612.1	0	0.0	24	45.8	2	16.0	2393	69673.9
CU OXYCHLOR SULFAT	378	60749.5	0	0.0	7	6086.0	3	124.0	388	66959.5
NITROGEN ELEMENTAL	420	63998.2	0	0.0	5	5.3	2	612.6	427	64616.1
FOLCID	405	60060.9	0	0.0	1	13.0	0	0.0	406	60073.9
DIURON	497	50681.3	16	553.6	56	2822.2	32	5400.5	601	59457.6
BORAX	24	16796.1	0	0.0	15	13218.8	25	28222.7	64	58237.6
TETRADIFON	1363	57742.7	0	0.0	3	6.3	1	25.0	1367	57774.0
PHOSPHAMIDON	1486	56207.9	0	0.0	44	103.6	3	27.5	1533	56339.0
TEPP	1802	55442.6	0	0.0	0	0.0	1	0.0	1803	55442.6
AMITROLE	693	32293.1	15	429.0	162	2176.3	160	19067.1	1030	53965.5
PHOSALONE	674	53545.7	0	0.0	0	0.0	0	0.0	674	53545.7
SUMMER OILS	70	51487.0	0	0.0	8	487.2	0	0.0	78	51974.2
DIATOMACEOUS EARTH	54	49720.7	0	0.0	0	0.0	0	0.0	54	49720.7
LEAD ARSENATE STAN	212	44211.3	0	0.0	19	1732.4	6	2177.4	237	48121.1
LIME SULFUR	43	45393.2	0	0.0	6	8.9	0	0.0	49	45402.1
META-SYSTOX-R	977	41991.8	0	0.0	30	67.8	5	143.0	1012	42202.6
ATRAZINE	248	16409.6	17	843.9	122	6702.7	62	16260.6	450	40316.8
LEAD ARSENATE BAS	171	37410.3	0	0.0	15	260.1	2	38.0	188	37697.2
DIPHENAMID	122	35120.6	0	0.0	0	0.0	18	2260.0	140	37380.6
POTASSIUM ELEMENTA	101	37011.5	0	0.0	0	0.0	0	0.0	101	37011.5
PHOSPHORUS PENTOXI	283	36877.6	0	0.0	5	2.4	0	0.0	288	36880.0
PYRAZON	136	35473.7	0	0.0	0	0.0	1	3.2	137	35476.9
METHOMYL	1320	34976.0	0	0.0	0	0.0	2	18.0	1322	34994.0
PHOSDRIN	1180	34367.5	0	0.0	0	0.0	0	0.0	1180	34367.5
CHLOROBENZILATE	442	32836.7	0	0.0	0	0.0	0	0.0	442	32836.7
METHOXYCHLOR	334	32457.6	0	0.0	0	0.0	0	0.0	334	32457.6
ARAMITE	418	19570.7	0	0.0	2	2.6	0	12761.0	420	32334.3
COPPER HYDROXIDE	298	29974.0	0	0.0	2	34.1	1	2079.0	301	32087.1
MCPA	406	31301.1	0	0.0	0	0.0	0	0.0	406	31301.1
TILLAM	66	27833.3	0	0.0	0	0.0	0	0.0	66	27833.3
NABAM	318	27308.3	0	0.0	0	0.0	0	0.0	318	27308.3
PLANAVIN	262	26052.4	0	0.0	1	4.0	0	0.0	263	26056.4
MINERAL OIL	2	6328.0	33	18578.6	4	139.8	0	0.0	39	25046.4
BROMACIL	127	5267.4	13	184.7	241	11787.0	37	5561.8	418	22800.9
PERTHANE	224	22729.4	0	0.0	0	0.0	0	0.0	224	22729.4
SODIUM TCA	30	18661.2	0	0.0	1	495.0	11	2797.7	42	21953.9
ZIRAM	120	21896.8	0	0.0	5	20.9	0	0.0	125	21917.7
SYSTOX	839	21506.6	0	0.0	6	8.0	1	0.8	846	21515.4
MANGANESE	650	20189.5	0	0.0	0	0.0	0	0.0	650	20189.5
ETHYLENE DIBROMIDE	25	19553.8	0	0.0	0	0.0	0	0.0	25	19553.8
SUTAN	76	19306.5	0	0.0	0	0.0	0	0.0	76	19306.5
DNBP AMMON. SALT	97	18512.3	0	0.0	0	0.0	0	0.0	97	18512.3
SULFATE OF POTASH	6	18300.3	0	0.0	0	0.0	0	0.0	6	18300.3

Table 2.1 - Continued

Substance	Agricultural		Vector Control		Structural and Residential		Government Agencies		Total	
	Records	Pounds	Records	Pounds	Records	Pounds	Records	Pounds	Records	Pounds
BALAN	181	18322.6	0	0.0	0	0.0	0	0.0	181	18322.6
EPTAM	95	17731.3	0	0.0	2	0.4	0	0.0	97	17731.7
TOK-25	63	17010.5	0	0.0	0	0.0	0	0.0	63	17010.5
BASIC ZINC SULFATE	133	16550.5	0	0.0	0	0.0	0	0.0	133	16550.5
RU-MELT	32	16476.1	0	0.0	0	0.0	0	0.0	32	16476.1
ZINC OXIDE	110	16382.3	0	0.0	0	0.0	0	0.0	110	16382.3
COPPER OXYCHLORIDE	89	6674.2	0	0.0	2	8432.0	0	0.0	91	15106.2
4(2,4-DB)	144	14749.8	0	0.0	0	0.0	0	0.0	144	14749.8
PCNB	263	14162.0	0	0.0	0	0.0	0	0.0	263	14162.0
CARBON DISULFIDE	1	155.3	0	0.0	0	0.0	47	13744.3	48	13899.5
DIELDRIN	486	11827.1	0	0.0	536	1984.0	3	1.5	1025	13812.6
ARSENIC ACID	35	12753.1	0	0.0	0	0.0	0	0.0	35	12753.1
VITAMIN B1	5	12565.0	0	0.0	0	0.0	0	0.0	5	12565.0
AMMATE	3	660.0	1	570.0	8	2649.0	31	7741.5	43	11620.5
BTS	435	11175.1	0	0.0	0	0.0	0	0.0	435	11175.1
SABADILLA	300	11151.1	0	0.0	0	0.0	0	0.0	300	11151.1
TEMIK	157	10896.0	0	0.0	0	0.0	5	169.5	162	11065.5
DDD	15	10609.5	0	0.0	0	0.0	0	0.0	15	10609.5
MAGNESIUM CHLORIDE	2	887.5	0	0.0	0	0.0	4	9223.0	6	10110.5
ORDRAM	59	9972.7	0	0.0	0	0.0	0	0.0	59	9972.7
FENAC	0	0.0	0	0.0	0	0.0	8	9928.2	8	9928.2
CARZOL SP	195	9652.6	0	0.0	0	0.0	0	0.0	195	9652.6
ZINEB	286	9473.0	0	0.0	0	0.0	2	1.2	288	9474.2
IPC	51	9466.1	0	0.0	0	0.0	0	0.0	51	9466.1
2,4,5-T	102	6916.7	2	11.0	2	173.0	9	2308.7	115	9409.4
SES	87	9374.6	0	0.0	0	0.0	0	0.0	87	9374.6
IMIDAN	230	8975.5	0	0.0	0	0.0	1	2.9	231	8978.4
CRYOLITE	8	6659.0	0	0.0	1	2304.0	0	0.0	9	8963.0
BIDRIN	161	8579.0	0	0.0	10	11.1	0	0.0	171	8590.1
DSMA	26	3903.5	1	13.5	3	127.5	8	4306.8	38	8351.3
CHLORINE	0	0.0	0	0.0	0	0.0	1	8327.5	1	8327.5
ENDOTHALL	503	8026.8	0	0.0	0	0.0	2	6.1	505	8032.8
OVEX	30	7940.2	0	0.0	0	0.0	0	0.0	30	7940.2
MOLASSES	14	7790.8	0	0.0	0	0.0	0	0.0	14	7790.8
BORON	21	7593.2	0	0.0	0	0.0	0	0.0	21	7593.2
ALDRIN	8	33.2	0	0.0	399	7156.5	1	0.1	408	7189.8
TCA	23	2930.7	0	0.0	1	4.5	21	4063.9	45	6999.1
POTASSIUM NITRATE	29	6965.2	0	0.0	0	0.0	0	0.0	29	6965.2
ETHYLENE DICHLORID	6	6011.0	0	0.0	0	0.0	0	0.0	6	6011.0
FOLEX	37	6505.9	0	0.0	0	0.0	0	0.0	37	6505.9
POLYRAM	43	6428.2	0	0.0	0	0.0	0	0.0	43	6428.2
DICAMBA	168	5828.3	0	0.0	7	140.0	10	355.1	185	6323.4
CALCIUM ARSENATE	8	6069.0	0	0.0	5	1.0	1	0.1	14	6070.1
MALEIC HYDRAZIDE	20	4266.8	0	0.0	3	1423.8	11	248.5	34	5939.1
NO CODE FOUND	5	5750.0	0	0.0	0	0.0	0	0.0	5	5750.0
EPN	60	5197.6	37	496.9	0	0.0	0	0.0	97	5694.5
BAYGON	0	0.0	80	5364.8	144	31.2	1	19.6	225	5415.6
IRON	169	5272.1	0	0.0	0	0.0	0	0.0	169	5272.1
AMMONIUM NITRATE	8	5140.0	0	0.0	1	9.0	0	0.0	9	5149.0
VAPAM	0	0.0	0	0.0	0	0.0	11	4925.0	11	4925.0
PRAMITOL-PROMETONE	21	1248.9	5	1159.0	7	293.2	7	2058.7	40	4759.8
MAGNESIUM	96	4742.8	0	0.0	0	0.0	0	0.0	96	4742.8
BETASAN	33	4611.9	0	0.0	1	8.0	0	0.0	34	4619.9
DNBP AMINE SALTS	22	4573.8	0	0.0	0	0.0	0	0.0	22	4573.8
MANGANESE SULFATE	104	4235.6	0	0.0	0	0.0	0	0.0	104	4235.6
BROMOXYNIL	111	4119.9	0	0.0	0	0.0	2	8.0	113	4127.9
DICRYL	1	4000.0	0	0.0	0	0.0	0	0.0	1	4000.0
GIBBERELLIC ACID	616	3914.0	0	0.0	0	0.0	0	0.0	616	3914.0
SODIUM POLYSULFIDE	14	3882.8	0	0.0	0	0.0	0	0.0	14	3882.8
BARBAN	79	3841.0	0	0.0	0	0.0	0	0.0	79	3841.0
MORESTAN	99	3755.7	0	0.0	0	0.0	1	0.0	100	3755.7
BOTRAN	65	3542.8	0	0.0	0	0.0	0	0.0	65	3542.8
RYANIA	250	3521.2	0	0.0	0	0.0	0	0.0	250	3521.2
PCP	1	208.0	4	33.2	12	70.4	15	3115.3	32	3426.9
TERRAZOLE	205	3187.7	0	0.0	0	0.0	0	0.0	205	3187.7
PANOGEN 15	47	3023.0	0	0.0	8	118.1	0	0.0	55	3141.1
MERCURY	3	3137.7	0	0.0	0	0.0	0	0.0	3	3137.7
COTORAN	20	3112.7	0	0.0	0	0.0	0	0.0	20	3112.7
PROMETRYNE	36	2976.0	0	0.0	0	0.0	0	0.0	36	2976.0
CARBON TETRACHLORI	8	2919.0	0	0.0	0	0.0	0	0.0	8	2919.0
DURSBAN	0	0.0	545	2447.7	393	416.9	0	0.0	938	2864.7
CALCIUM NITRATE	1	2850.0	0	0.0	0	0.0	0	0.0	1	2850.0
RAMROD	10	2761.2	0	0.0	0	0.0	0	0.0	10	2761.2
TENORAN	8	2698.0	0	0.0	0	0.0	0	0.0	8	2698.0
LINURON	33	2049.8	1	29.0	22	487.1	2	41.0	58	2606.9
CARBON	1	2340.0	0	0.0	0	0.0	1	160.0	2	2500.0
DEF	1	136.0	1	54.4	9	2185.0	0	0.0	11	2375.4
DNAP-DNBP MIXTURE	5	2280.0	0	0.0	0	0.0	0	0.0	5	2280.0
AVADEX BW	14	2243.0	0	0.0	0	0.0	0	0.0	14	2243.0
HYVAR	11	1485.2	3	262.7	7	228.8	3	156.4	24	2133.1
SILVEX	12	1460.0	0	0.0	3	551.3	12	107.9	27	2119.2
DINITROPHENOL	20	2037.2	0	0.0	0	0.0	0	0.0	20	2037.2
SODIUM NITRATE	0	0.0	1	15.0	0	0.0	20	1773.2	21	1788.2
SODIUM PCP	5	1764.1	0	0.0	0	0.0	0	0.0	5	1764.1
DASANIT	6	1734.2	0	0.0	0	0.0	0	0.0	6	1734.2
TORDON	7	161.4	0	0.0	0	0.0	21	1539.1	28	1700.5
CHLORDANE	36	789.3	0	0.0	7	877.9	0	0.0	43	1667.2
FERBAM	9	1561.4	0	0.0	0	0.0	0	0.0	9	1561.4
MONURON	7	169.6	0	0.0	6	225.6	17	1079.9	30	1475.1
ZINC MANGANESE	20	1432.4	0	0.0	0	0.0	0	0.0	20	1432.4
OIL OF CITRONELLA	1	1350.0	0	0.0	0	0.0	0	0.0	1	1350.0
LINDANE	14	384.6	0	0.0	515	904.8	1	11.2	530	1300.6
TANDEX TM	31	483.2	0	0.0	36	730.8	2	8.4	69	1222.4
MOLYBDENUM	32	1107.8	0	0.0	0	0.0	0	0.0	32	1107.8
TRYSBEN, TCB	2	33.4	0	0.0	0	0.0	12	1015.4	14	1048.8
DICHLONE	70	1008.9	0	0.0	0	0.0	0	0.0	70	1008.9
BASIC COPPER CARBO	21	1005.0	0	0.0	0	0.0	0	0.0	21	1005.0
VIKANE	0	0.0	0	0.0	18	989.1	0	0.0	18	989.1
LASSO	8	984.6	0	0.0	0	0.0	0	0.0	8	984.6
FERROUS SULFATE	97	944.4	0	0.0	0	0.0	0	0.0	97	944.4
ZINC PHOSPHIDE	1	28.5	0	0.0	1	0.0	67	913.5	69	942.0
ABATE	8	762.9	83	164.4	0	0.0	3	0.1	94	927.4
DNOCHP	5	907.4	0	0.0	0	0.0	0	0.0	5	907.4
COPPER OLEATE-ABIE	7	864.9	0	0.0	0	0.0	0	0.0	7	864.9
SODIUM FLUOSILICAT	9	861.7	0	0.0	0	0.0	0	0.0	9	861.7
GARDONA	16	824.8	0	0.0	0	0.0	1	1.6	17	826.4
SESAMOLIN	1	810.0	0	0.0	0	0.0	0	0.0	1	810.0
DNAP	4	787.5	0	0.0	0	0.0	0	0.0	4	787.5
TRIETHYLENE GLYCOL	2	756.0	0	0.0	0	0.0	0	0.0	2	756.0
DYRENE	8	710.5	0	0.0	0	0.0	0	0.0	8	710.5
NAPHTH ACETIC ACID	17	703.3	0	0.0	0	0.0	0	0.0	17	703.3
BETANAL-PHENMEDIP	25	696.1	0	0.0	0	0.0	0	0.0	25	696.1
DMPA	8	654.7	0	0.0	0	0.0	0	0.0	8	654.7
CIPC	8	649.8	0	0.0	0	0.0	0	0.0	8	649.8
MIREX	8	647.6	0	0.0	0	0.0	0	0.0	8	647.6

Table 2.1 - Continued

Substance	Agricultural		Vector Control		Structural and Residential		Government Agencies		Total	
	Records	Pounds	Records	Pounds	Records	Pounds	Records	Pounds	Records	Pounds
NOREA	13	636.0	0	0.0	0	0.0	1	8.0	13	644.0
SULFAVENE	1	640.0	0	0.0	0	0.0	0	0.0	1	640.0
CRAG FLY REPELLANT	2	99.0	0	0.0	0	0.0	1	536.0	3	635.0
COPPER CARBONATE	17	590.6	0	0.0	0	0.0	0	0.0	17	590.6
ZINC COPPER	3	583.7	0	0.0	0	0.0	0	0.0	3	583.7
AVADEX	3	550.0	0	0.0	0	0.0	0	0.0	3	550.0
PIVAL	0	0.0	0	0.0	106	0.7	27	432.2	133	432.9
ENDRIN	28	421.4	0	0.0	0	0.0	0	0.0	28	421.4
DNOC	7	415.4	0	0.0	0	0.0	0	0.0	7	415.4
ALFALFA SEED	1	399.6	0	0.0	0	0.0	0	0.0	1	399.6
SODIUM METABORATE	0	0.0	0	0.0	1	377.0	0	0.0	1	377.0
GENITE 923	6	363.2	0	0.0	2	0.1	0	0.0	8	363.3
LANDAST	7	343.6	0	0.0	0	0.0	0	0.0	7	343.6
STRYCHNINE	1	0.0	0	0.0	221	42.3	145	299.9	367	342.2
RED OR WH PHOSPHOR	0	0.0	0	0.0	0	0.0	21	338.5	21	338.5
NPA	2	334.2	0	0.0	0	0.0	0	0.0	2	334.2
PENTANE	2	325.5	0	0.0	0	0.0	0	0.0	2	325.5
1080	0	0.0	0	0.0	3	142.0	62	182.0	65	324.0
NO CODE FOUND	14	322.8	0	0.0	0	0.0	0	0.0	14	322.8
DDVP	2	57.5	11	72.0	1201	169.5	1	0.5	1215	299.4
SINBAR	7	263.6	0	0.0	0	0.0	0	0.0	7	263.6
AZAK	1	243.8	0	0.0	0	0.0	0	0.0	1	243.8
PHENYL MERC BORATE	1	239.1	0	0.0	0	0.0	0	0.0	1	239.1
NUTROPHUS	3	238.2	0	0.0	0	0.0	0	0.0	3	238.2
TETRADAN	1	236.0	0	0.0	0	0.0	0	0.0	1	236.0
2,4-DP	3	46.0	0	0.0	0	0.0	3	176.0	6	222.0
SODIUM CHLORIDE	1	212.0	0	0.0	0	0.0	0	0.0	1	212.0
VERNAM	6	208.7	0	0.0	0	0.0	0	0.0	6	208.7
THIRAM	8	30.8	0	0.0	8	154.2	0	0.0	16	185.0
FATTY ALCOHOLS	4	182.2	0	0.0	0	0.0	0	0.0	4	182.2
AMMONIA	6	175.9	0	0.0	4	1.9	0	0.0	10	177.8
NO CODE FOUND	1	177.1	0	0.0	0	0.0	0	0.0	1	177.1
2,4-D,DIMETHYLAMIN	1	140.0	0	0.0	0	0.0	0	0.0	1	140.0
PHENOTHIAZINE	1	133.0	0	0.0	0	0.0	0	0.0	1	133.0
CPA	2	131.3	0	0.0	0	0.0	0	0.0	2	131.3
METHYLISOTHIOCYANA	1	120.0	0	0.0	0	0.0	0	0.0	1	120.0
AVITROL 200	52	112.6	0	0.0	13	5.2	0	0.0	65	117.9
LEAD	3	116.2	0	0.0	0	0.0	0	0.0	3	116.2
PARNON	17	110.9	0	0.0	0	0.0	0	0.0	17	110.9
PHOSTOXIN	16	105.4	0	0.0	0	0.0	0	0.0	16	105.4
POTASSIUM CYANATE	1	103.5	0	0.0	0	0.0	0	0.0	1	103.5
PIPERONYL BUTOXIDE	5	47.6	0	0.0	60	19.1	4	30.1	69	98.8
WARFARIN	0	0.0	0	0.0	7	0.2	30	98.2	37	98.6
KORUN	1	60.0	0	0.0	0	0.0	4	38.4	5	98.4
MCPP,DIETHANOLAMIN	1	89.3	0	0.0	0	0.0	0	0.0	1	89.3
DIQUAT	3	70.8	0	0.0	0	0.0	5	15.3	8	86.1
NAA, SALT	1	84.9	0	0.0	0	0.0	0	0.0	1	84.9
CERESAN L	9	51.7	0	0.0	2	30.8	0	0.0	11	82.5
KARATHANE	9	81.6	0	0.0	0	0.0	0	0.0	9	81.6
DYFONATE	1	80.0	0	0.0	0	0.0	0	0.0	1	80.0
NO CODE FOUND	1	79.2	0	0.0	0	0.0	0	0.0	1	79.2
PARAFORMALDEHYDE	1	77.9	0	0.0	0	0.0	0	0.0	1	77.9
BINAPACRYL	2	76.0	0	0.0	0	0.0	0	0.0	2	76.0
TRIPHENYLTIN HYDRO	9	75.4	0	0.0	0	0.0	0	0.0	9	75.4
ETHYLENE DICHLORID	10	72.1	0	0.0	0	0.0	0	0.0	10	72.1
CASORON	2	65.0	0	0.0	0	0.0	1	5.4	3	70.4
FUNDAL	8	70.0	0	0.0	0	0.0	0	0.0	8	70.0
NIACIDE	1	65.0	0	0.0	0	0.0	0	0.0	1	65.0
CDAA	1	64.8	0	0.0	0	0.0	0	0.0	1	64.8
CERESAN M	34	60.5	0	0.0	0	0.0	0	0.0	34	60.5
PYRETHRINS	4	45.2	0	0.0	89	7.2	4	6.0	97	58.5
B-NINE	1	50.0	0	0.0	0	0.0	0	0.0	1	50.0
00000000000000000000000	0	0.0	0	0.0	0	0.0	1	46.0	1	46.0
NUTRIENT D	1	44.0	0	0.0	0	0.0	0	0.0	1	44.0
CALCIUM CYANAMIDE	1	40.0	0	0.0	3	3.2	0	0.0	4	43.2
LYE	1	36.0	0	0.0	0	0.0	0	0.0	1	36.0
ALROSEPT MBC	1	30.0	0	0.0	0	0.0	0	0.0	1	30.0
MGK REPELLENT 11	1	26.3	0	0.0	0	0.0	0	0.0	1	26.3
RATICATE	0	0.0	0	0.0	0	0.0	1	26.0	1	26.0
KEPONE	0	0.0	2	26.0	0	0.0	0	0.0	2	26.0
FUMARIN	1	24.0	0	0.0	0	0.0	0	0.0	1	24.0
THIABENDAZOLE	6	23.1	0	0.0	0	0.0	0	0.0	6	23.1
HYAMINE 10X	1	21.4	0	0.0	0	0.0	0	0.0	1	21.4
ROTENONE	1	20.0	0	0.0	0	0.0	0	0.0	1	20.0
METHYL MERC BENZOA	1	18.9	0	0.0	0	0.0	0	0.0	1	18.9
SEMESAN BEL	7	18.6	0	0.0	0	0.0	0	0.0	7	18.6
DIFOLTAN	1	18.4	0	0.0	0	0.0	0	0.0	1	18.4
SULFOTEPP	1	18.0	0	0.0	0	0.0	2	0.1	3	18.1
NIAGRA FUMATIZ	1	0.1	0	0.0	4	0.6	2	16.0	7	16.7
BENZENE	1	12.8	2	3.1	0	0.0	0	0.0	3	15.9
CYANOGAS	1	9.4	0	0.0	8	6.2	0	0.0	9	15.6
DEET, OFF	0	0.0	0	0.0	3	10.0	0	0.0	3	10.0
SPERGON	1	10.0	0	0.0	0	0.0	0	0.0	1	10.0
TYROTHRICIN	1	9.6	0	0.0	0	0.0	0	0.0	1	9.6
NDA	5	8.9	0	0.0	0	0.0	0	0.0	5	8.9
BUTOXYETHANOL	0	0.0	0	0.0	1	8.0	0	0.0	1	8.0
PMB	1	8.0	0	0.0	0	0.0	0	0.0	1	8.0
MISC. MINOR ELEMEN	6	8.0	0	0.0	0	0.0	0	0.0	6	8.0
BUTONATE	1	7.5	0	0.0	0	0.0	0	0.0	1	7.5
CARBOFURAN	4	7.0	0	0.0	0	0.0	0	0.0	4	7.0
AMMONIUM THIOCYANA	0	0.0	0	0.0	0	0.0	1	6.3	1	6.3
KERB	3	6.3	0	0.0	0	0.0	0	0.0	3	6.3
STREPTOMYCIN	4	5.9	0	0.0	0	0.0	0	0.0	4	5.9
CALOMEL	0	0.0	0	0.0	1	5.0	0	0.0	1	5.0
UREA	0	0.0	0	0.0	0	0.0	1	4.8	1	4.8
ARSENIC SULFIDE	1	4.0	0	0.0	0	0.0	0	0.0	1	4.0
METALDEHYDE	0	0.0	0	0.0	7	3.2	3	0.5	10	3.7
MECOPEX MCPPK	0	0.0	0	0.0	2	3.1	0	0.0	2	3.1
AURAMINE	2	3.0	0	0.0	0	0.0	0	0.0	2	3.0
DIPHACIN	0	0.0	0	0.0	428	3.0	7	0.0	435	3.0
MYPU	1	2.9	0	0.0	0	0.0	0	0.0	1	2.9
THALLIUM SULFATE	0	0.0	0	0.0	0	0.0	1	2.5	1	2.5
AGRISTREP	1	2.1	0	0.0	0	0.0	0	0.0	1	2.1
STRYCHNINE SULFATE	0	0.0	0	0.0	0	0.0	5	2.0	5	2.0
PINE OIL	0	0.0	0	0.0	4	1.9	0	0.0	4	1.9
LIGNASAN-X	0	0.0	0	0.0	1	1.0	0	0.0	1	1.0
DIAMMONIUM PHOSPHA	1	0.9	0	0.0	0	0.0	0	0.0	1	0.9
METHYL SALICYLATE	0	0.0	0	0.0	1	0.8	0	0.0	1	0.8
TERRAMYCIN	1	0.7	0	0.0	0	0.0	0	0.0	1	0.7
STARLICIDE	1	0.1	0	0.0	0	0.0	2	0.3	3	0.4
FRUITONE T, COLOR	1	0.2	0	0.0	0	0.0	0	0.0	1	0.2
MGK 264	0	0.0	0	0.0	0	0.0	1	0.1	1	0.1
TOTAL	154884	76271520.4	3497	1755562.3	15148	833923.8	2299	4968036.7	177706	83825849.1

the materials reported; vector control accounted for 2% of the records and 2% by weight; structural and residential accounted for 9% of the records and 1% by weight; government agencies accounted for 1% of the records and 6% by weight.

Mercury-treated seed is the weight of the treated seed, not of the mercury compound itself. Mercurials will be discontinued for seed treatment after 1971 (Fielder, 1971), and only existing inventories of mercury-treated seed may be used in 1972. This is probably the most reasonable method of disposing of these hazardous materials. It might be noted, though, that the hazard associated with these materials has been confused by certain widely-publicized incidents (Dunlap, 1971).

The discovery of excessive levels of mercury in commercial and game fish in Canada and the United States in 1970 came at a time of extreme public sensitivity to news about environmental toxicants. However, there is no reason to attribute the "mercury problem" of aquatic and marine organisms to the mercurial fungicides used as seed dressings in agriculture. The principal source of mercury in fish involves the conversion of elemental mercury to methyl mercury by benthic organisms, and the incorporation of methyl mercury into the biota. Mining operations and the discharge of elemental mercury from certain industrial processes such as the electrodes of chlor-alkali plants, are the most common sources of mercury added to the naturally occurring environmental burden of this element.

In 1969 a farmer in New Mexico fed mercury-treated seed grain to hogs and poisoned his family by feeding them the pork (Curley, 1971). Pathetic incidents of this sort (Eyle, 1971) highlight the need for safeguards surrounding the storage of any hazardous material and ways of guaranteeing that they will be used only for their intended purpose. Whether such incidents should have had a substantial impact on public policy concerning the legitimate use of mercurials for the protection of seeds from fungi is another question.

A more common hazard of mercurial fungicides on seeds is the seemingly inevitable poisoning of some nontarget organisms, including game birds, as they consume the treated seed. This is a true environmental cost of such treatment, and should be included in cost-benefit calculations of mercurial seed-treatment.

Because the four categories of records in our data file differed slightly in the nature of the information reported, and because of the particular focus of the present case study, the agricultural records were studied in greater detail than were the others. In addition, some of the materials reported in Table 2.1 were considered of only secondary interest or importance for the present case study because the materials were applied in relatively small quantities, or were not considered to be pesticides (e.g., spreaders), or were not considered particularly hazardous (e.g., petroleum solvents).

On the basis of the above-mentioned criteria, the forty-eight pesticides in Table 2.2 were selected for more intense study and additional verification. The concentration and dose rate (pounds per acre) were checked for each record of each of these chemicals. The present case study excluded those records that seemed excessive and therefore most likely to contain errors (attributable to misplaced decimal points, keypunch error, erroneous specification of pounds of active ingredient per gallon of formulation, etc.). Such exclusion eliminated fifty-four records.

On the basis of pounds applied of the forty-eight pesticides in Table 2.2, the eight counties of the San Joaquin Valley are rated in following descending order of pesticide use: Fresno>> Kern > Tulare > San Joaquin > Kings > Merced > Stanislaus >> Madera. Of the total pounds applied, Fresno used 38.4%. The counties are listed in Table 2.2 from north to south in the valley, from San Joaquin County to Kern County. Heavy use of toxaphene and DDT is associated with Fresno, Kings, and Kern Counties, in the central to southern portions of the valley, where cotton is a major crop. Def-Defoliant, used to defoliate cotton prior to harvest, shows a similar use pattern. The pesticides in Table

Table 2.2 Some Pesticides Used in Agriculture in San Joaquin Valley, 1970

Chemical	Pounds Reported, by Counties								8-County Totals		
	San Joaquin	Stanislus	Merced	Madera	Fresno	Kings	Tulare	Kern	Pounds	Apps	Acres
Toxaphene	16,297.31	45.00	7,618.80	2,551.01	1,174,071.00	285,156.52	19,956.74	260,055.54	1,765,741.92	3164	486,915.40
DDT	13,624.09	1,231.45	2,988.75	2,738.00	559,884.12	145,499.89	11,788.90	132,044.07	869,789.26	3652	475,681.29
Telone	294,398.00	145,294.53	23,280.00	0.00	199,313.84	46,332.00	102,034.43	9.840.00	820,492.80	245	7,421.02
D-D Mixture	179,283.67	16,324.60	328,039.80	30,588.16	167,747.06	0.00	23,498.00	10,250.00	755,731.29	225	4,763.38
Parathion	44,249.87	85,758.01	47,280.20	21,247.61	155,457.26	27,860.01	147,679.05	60,369.11	589,901.11	10,835	460,071.87
Kelthane	39,449.29	40,934.08	16,797.79	6,204.30	141,130.51	51,885.48	84,243.05	130,196.54	510,841.06	5198	409,223.17
Methyl Bromide	19,099.20	65,495.37	496.20	36,025.20	138,191.98	0.00	74,681.98	87,958.54	421,948.47	221	5,115.26
Carbaryl	80,281.97	32,762.84	21,508.97	8,332.51	45,090.96	10,889.33	87,015.58	40,252.59	326,134.74	2843	127,336.37
2, 4-D	62,967.73	26,964.44	17,816.35	15,143.40	80,965.85	62,933.03	22,494.73	13,967.34	303,252.92	3612	409,097.20
Malathion	16,632.31	24,838.65	10,098.47	18,907.72	106,683.68	18,737.82	51,066.38	42,627.01	289,592.04	2903	197,190.62
Phorate	697.00	1,709.40	6,462.07	10,414.36	114,469.60	29,769.66	45,172.02	59,434.65	268,128.75	3368	304,472.08
Chloropicrin	5,426.35	19,152.67	108,442.40	0.00	47,017.90	0.00	21,869.98	49,702.03	251,166.33	189	1,913.49
Guthion	22,356.43	24,991.76	11,322.16	8,158.13	31,450.60	1,583.47	88,350.33	60,185.17	248,407.97	6555	244,139.18
Def-Defoliant	0.00	687.20	6,553.13	4,054.03	86,498.48	28,915.04	14,915.04	101,162.26	242,820.67	1631	165,737.05
Maneb	15,820.77	6,851.12	1,645.50	6,294.50	72,990.67	5,058.77	13,021.84	165,383.61	242,066.78	1449	110,540.01
Methyl Parathion	2,392.01	8,904.02	4,898.78	2,584.26	130,397.12	5,647.43	4,486.46	63,231.44	222,541.53	3545	313,265.85
Trifluralin	8,814.11	1,012.65	5,637.06	8,984.44	83,710.67	5,104.64	16,571.79	87,557.76	217,393.12	2160	169,153.94
DBCP	84,696.86	3,013.66	9,391.94	24,391.18	61,712.68	579.42	7,759.78	9,646.86	201,192.29	374	14,449.49
Endosulfan	16,736.21	15,345.49	8,058.84	2,814.58	85,123.89	10,685.79	6,043.52	46,895.14	191,703.45	2686	201,786.10
Ethion	2,655.36	7,443.88	14,056.14	13,551.88	69,076.97	3,419.19	73,178.98	5,564.92	188,947.31	3022	133,542.71
Naled	5,862.39	17,640.29	4,159.80	8,967.15	64,836.86	28,308.95	25,455.50	29,386.12	184,637.06	4110	203,055.78
Delnav	32.50	319.25	62.00	4,605.60	17,444.75	96.64	99,506.49	23,231.25	145,298.47	1614	51,560.98
Sinox	6,518.11	1,845.66	3,949.64	3,185.88	68,898.59	8,298.39	7,639.11	40,663.88	140,999.27	1113	86,414.22
Captan	5,678.12	28,785.10	7,331.21	3,117.65	73,593.93	273.40	7,342.67	4,867.15	130,989.22	773	18,098.95
Dylox	6,940.22	17,328.45	1,678.40	4,197.83	55,970.74	20,184.60	7,401.05	13,573.07	127,274.37	1066	110.607.00
Dimethoate	3,568.88	4,440.19	3,205.21	2,728.97	36,754.24	6,896.80	40,850.76	19,926.03	118,371.07	3615	224,176.43
Diazinon	18,409.87	9,841.13	4,360.73	7,018.21	10,274.64	1,234.42	16,277.36	31,653.78	99,070.14	1913	77,069.24
Azodrin	137.00	245.08	291.13	2,288.26	35,019.60	18,318.73	14,701.43	25,527.87	96,529.10	1648	167,694.46
Sodium Arsenite	30,883.74	6,327.40	4,683.21	10,171.17	20,665.14	120.00	8,984.29	9,226.83	91,061.78	589	16,394.41
Disyston	9,041.34	2,345.91	1,018.01	4,602.74	5,422.54	8,153.55	33,122.20	19,642.48	83,348.77	1290	102,085.40
Propanil	2,366.45	1,054.00	28,526.39	2,854.19	40,552.91	0.00	360.00	120.00	75,833.94	183	18,281.60
DNBP	3,270.69	1,912.52	605.00	2,878.52	29,991.50	56.25	7,417.03	29,248.32	75,379.84	485	36,255.61
Dalapon	2,925.83	78.20	2,111.85	1,903.65	35,824.36	21,416.75	8,789.22	2,261.93	75,311.78	391	23,455.44
Omite	2,351.67	17,848.34	6,633.50	1,510.37	10,731.49	5,612.82	15,902.15	11,643.19	72,233.52	1602	49,765.23
Dacthal	0.00	4,300.95	461.81	180.00	21,042.70	3.352.50	1,722.22	38,840.24	69,900.42	162	8,781.10
Simazine	1,328.31	946.88	1,208.44	6,851.24	13,809.31	13.60	24,338.33	21,204.47	69,700.57	1316	47,643.12
Carbophenothion	7,299.66	12,928.57	3,162.91	11,258.72	19,483.20	483.65	4,215.87	10,779.50	69,612.07	2367	79,556.75
Paraquat	1,675.64	357.10	1,758.41	2,899.00	26,674.29	11,544.72	6,633.22	15,246.23	66,788.61	3003	310,860.59
Polcid	3,306.92	16,021.55	1,788.50	0.00	3,630.24	296.05	636.40	34,381.25	60,060.90	405	34,083.70
Tetradifon	0.00	96.64	697.38	6,321.51	20,284.39	3,519.06	4,450.52	22,373.23	57,742.72	1363	87,628.26
Phosphamidon	4,953.21	3,744.96	1,987.21	2,134.60	5,752.56	68.41	26,576.72	10,990.23	56,207.89	1486	59,467.54
Tepp	511.76	2,723.57	2,928.24	299.83	31,715.66	1,675.76	8,824.72	6,763.01	55,442.56	1802	92,969.94
Phosalone	2,777.87	3,024.47	2,572.54	5,263.49	15,515.21	666.79	7,875.12	15,850.17	53,545.67	674	24,215.57
Diuron	12,719.65	524.80	456.29	1,324.88	14,790.54	1,916.80	10,761.48	8,166.85	50,681.28	497	29,051.53
Lead Arsenate Stand.	14.00	0.00	0.00	1,520.00	40,109.65	1,491.30	1,076.34	0.00	44,211.29	212	7,057.10
Meta-Systox-R	687.60	1,033.72	267.25	593.49	26,718.17	874.30	2,273.77	9,543.52	41,991.81	977	107,907.44
Lead Arsenate Basic	415.58	0.00	244.42	727.40	17,150.03	2,153.74	14,962.00	1,765.10	37,418.27	171	4,647.51
Ansar 170	584.24	278.00	2,694.09	8,202.11	4,422.30	7,676.18	7,206.33	6,336.07	37,399.32	361	17,553.02

2.2 are listed in decreasing order of total pounds of agricultural use. In this sequence, Telone, D-D mixture, methyl bromide, and chloropicrin rank 3, 4, 7, and 12. However, the total acres to which these four chemicals were applied (the right hand column of Table 2.2) are comparatively small. While the dose rate for other pesticides is typically in the range of one to three pounds of active ingredient per acre, these four compounds are commonly applied directly to the soil at the rate of 100 pounds or more per acre for nematode control (Lyndall and Mather, 1971). Parathion ranks fifth in Table 2.2, but is the first of the organophosphorus pesticides in pounds used in the San Joaquin Valley (and in California). With 10,835 agricultural applications in the valley in 1970, parathion is also the most frequently used pesticide in Table 2.2. Its high acute toxicity to man makes this compound a source of serious concern to environmental and occupational health authorities.

For a view of the crops that are the principal users of chemical pesticides in the San Joaquin Valley, Table 2.3 shows the top 26 crops in terms of the pounds of the 48 selected pesticides. When the same field received application on more than one occasion, its acreage was counted each time, and when more than one chemical was applied simultaneously, each was entered separately in Table 2.3, as if the constituents had been applied on separate occasions. The 48 chemicals were used on a toal of 117 commodities or crops.

Pesticide treatment of the 26 crops in Table 2.3 used 10,361,638 pounds of the 48 chemicals listed in Table 2.2. This is 98.5% of the eight-county total of these pesticides (10,522,282 pounds). Thus, the use of the pesticides tends to be concentrated on a comparatively few crops.

Cotton is the top crop in terms of pounds of the 48 pesticides applied in the San Joaquin Valley, accounting for 30% of the total, in spite of the fact that cotton production is concentrated in the southern and western part of the Valley. One could speculate on whether government price-support policies might be inadvertently providing economic incentives to excessive pesticide use. If the cost of the "externalities" of pesticide use could be estimated, then government policymakers would be in an improved position to foster the judicious use of pesticides.

Table 2.3 Some crops protected by chemicals
San Joaquin Valley, 1970

CROP	Selected Pesticides		
	APPS	ACRES	POUNDS
Cotton	19,363	2,087,176	3,181,577
Alfalfa seed	4,795	635,934	1,018,566
Fallowland	2,035	179,849	765,614
Oranges	11,059	299,529	696,267
Grapes	10,534	377,941	651,482
Tomatoes	3,276	229,620	504,514
Sugar beets	735	82,804	408,699
Almonds	3,096	147,774	332,060
Peaches	5,647	144,537	321,611
Sweet potatoes	146	1,504	319,382
Alfalfa hay	3,340	388,734	315,751
Potatoes	2,856	237,816	278,938
Barley	1,560	243,438	175,546
Beets	316	25,923	166,588
Beans, dry	2,425	166,855	152,662
Nursery plantings	355	19,998	139,400
Strawberries	226	2,008	136,213
Nectarines	1,838	29,805	127,216
Lettuce	1,926	109,902	99,921
Melons	1,050	97,196	95,248
Milo	1,464	110,537	990,661
Walnuts	2,113	55,768	90,099
Rice	274	26,927	76,973
Corn	725	66,024	76,066
Onions	768	39,533	73,883
Plums	1,799	28,355	72,701

The individual agricultural pesticide use records have space for one chemical, one crop or commodity, and up to three pests. Table 2.4 shows the frequency with which the chemicals listed in Table 2.2 were applied against particular pests. When an application was directed against more than one pest, the application, acres, and pounds were included in the totals for each pest in compiling Table

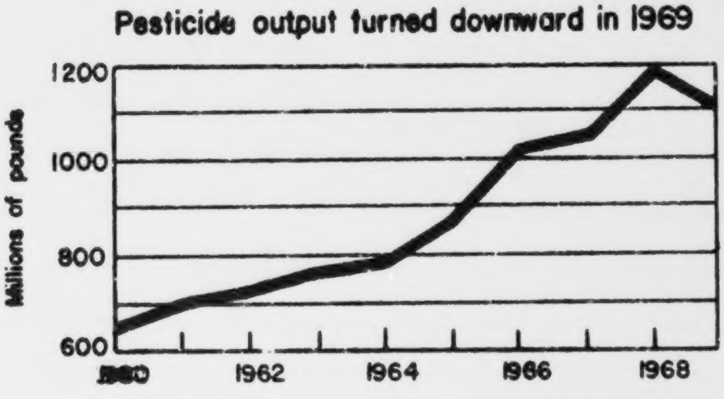
Table 2.4 Some Agricultural Pests Managed by Chemicals
San Joaquin Valley, 1970

Pest	Selected Pesticides		
	Appls.	Acres	Pounds
Nematodes, non-specified	1118	29692	2343963
Lygus bugs	10549	1383133	2193313
Mites, non-specified	28336	1662490	2139432
Worms, non-specified	11892	847273	1362971
Weeds, non-specified	9877	868029	1353049
Aphids, non-specified	8401	745134	769255
Bollworm	1184	180780	439170
Scales, non-specified	5944	141150	415440
Thrips, non-specified	7248	256167	396360
Leaf Hoppers, non-specified	6474	294954	310951
Stinkbugs, non-specified	880	127359	236168
Blight, non-specified	1781	156246	209873
Twig borer	2795	103949	189712
Citrus Thrips	3061	79784	174544
Pox	81	754	169822
Armyworms, non-specified	1202	106182	160011
Brown rot	1298	29168	150380
Fungus	471	26815	150236
Loopers, non-specified	1502	101326	120166
Oriental fruit moth	1755	50127	87865
Potato tuberworm	1149	82497	84235
Corn earworm	461	43023	83872
Cutworms, non-specified	1382	67628	76127
Peach twig borer	992	32297	71308
Beet armyworm	230	35256	64820
Mildew, non-specified	876	31880	62959
Insects, non-specified	229	18988	58098
Two-spotted spider mite	242	65087	56852
Dead arm	408	11864	53209
Disease, non-specified	32	912	52061
San Jose Scale	953	22352	50630
Measles	277	9742	49024
Leaf rollers, non-specified	613	23855	38772
Omnivorous leaf roller	300	11311	30923
Leaf curl	343	7870	27754
Pink bollworm	52	6466	25506
Alfalfa weevil	448	35850	24969
Pea aphid	98	26448	24280
Moth, non-specified	403	23208	23413
Potato Aphid	172	21014	21596

2.4. Also, when the same field received application on more than one occasion, its acreage was counted each time an application was made. When more than one chemical was applied simultaneously, it was treated, in Table 2.4, the same as if the constituents had been applied separately. Table 2.4 lists only the top 40 pests, in terms of total pounds of the selected pesticides. These chemicals were used against a total of 169 different pests.

The pest list in Table 2.4 illustrates one of the limitations inherent in the pesticide reporting system, viz., the limitations of those filing the reports. Although the pest codes make provision for hundreds of pests, the broader categories, such as "mites, non-specified," are favored over more refined entomological identification of the pests.

In August 1970, Chemical and Engineering News announced: "After eleven years of uninterrupted growth, production of pesticides slipped 7.4% last year to 1.1 billion pounds, according to a just-released report by the U. S. Tariff Commission. Sales (at the manufacturers' level) were also down, amounting to 929 million pounds, valued at $851 million, compared to 960 million pounds, valued at $849 million, in 1968." The announcement was accompanied by a graph of pesticide production (Figure 2.2).



Source: U.S. Tariff Commission

Figure 2.2

In February 1971, the Agriculture Stabilization and Conservation Service of USDA published "The Pesticide Review 1970," reporting increasing restrictions on and scrutiny of pesticide use, and the search for safer methods of pest management. That report also quoted the U. S. Tariff Commission figures referred to above.

In September 1971, the U. S. Tariff Commission published preliminary figures for 1970. That report stated: "U. S. production of pesticides and related products in 1970 amounted to 1,034 million pounds--6.4 percent less than the 1,104 million pounds reported for 1969. Sales in 1970 were 881 million pounds, valued at $870 million, compared with 929 million pounds, valued at $851 million, in 1969." Table 2.5 compares the 1970 use of some pesticides in the San Joaquin Valley (all the uses shown in Table 2.1) with use for the entire state of California, and with sales figures for the entire nation as gleaned from the preliminary report of the U. S. Tariff Commission.

Detailed figures on the history of individual pesticide use in the San Joaquin Valley are not generally available. Our agricultural file of pesticide use in Fresno County for 1968, however, is comparable to the 1970 data, in numbers of applications and acres. Table 2.6 shows changing patterns of pesticide use, reflected in comparison between these two files of data.

Substantial reductions in the use of toxaphene and DDT in the San Joaquin Valley between 1968 and 1970 are due to several factors, including cancellation of their registration for use on many crops, increasing pest resistance, and the availability of alternative chemicals.

Methyl and ethyl parathion showed substantial increases. These highly toxic broad-spectrum organophosphorus insecticides have taken over a significant part of the work for which DDT was formerly used. Phorate, another organophosphate, showed a spectacular increase, and meta-systox, dimethoate, guthion, and ethion all experienced notable increases in use.

Table 2.5 Comparisons of Pesticide Use and Sales

Pesticide	1970 Use (1,000 Pounds) San Joaquin Valley	1970 Use (1,000 Pounds) California[a]	1970 U.S. Sales (1,000 Pounds)
Aldrin-toxaphene group:	1,796	3,483	84,225
Aldrin	7.2	53.7	
Chlordane	8.4	661.3	
Dieldrin	13.4	95.6	
Endrin	.4	12.9	
Heptachlor	0.0	.5	
Toxaphene	1,766.2	2,659.3	
2,4-D group[b]	303	1,217	59,700
Dithiocarbamic acid salts:	285	644	40,013[c]
Ferbam	1.6	4.2	
Maneb	242.1	503.2	
Metham (Vapam)	4.9	9.4	
Nabam	27.3	42.6	
Zineb	9.5	84.6	
Methyl parathion	223	930	39,869
DDT	870	1,165	34,019
Methyl bromide	422	3,102	21,790
Parathion	590	1,172	15,504
Kelthane	511	645	
Carbaryl	327	892	
Malathion	654	1,100	
Phorate	270	481	
Guthion	248	468	
Trifluralin	217	241	
Endosulfan	192	508	
Ethion	189	220	
Naled	186	316	
Delnav	145	184	
Diazinon	105	265	
Azodrin	97	158	
Propanil	76	76	
Dalapon	102	242	
Simazine	102	312	
Paraquat	80	137	
TEPP	55	65	
Diuron	59	112	

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[a] Taken from California Dept. of Agriculture (1971), not directly from the data bank.

[b] Includes 2,4-D acid and its esters and salts.

[c] "Includes ferbam, maneb, metham, nabam, and zineb, plus the remaining dithiocarbamates which are used chiefly as pesticides." (U.S. Tariff Commission, 1971, p. 4).

Table 2.6 Changing Patterns of Pesticide Use in Agriculture Fresno County, 1968 and 1970

Chemical	1968		1970		Change 1968–70
	Appls.	Acres	Appls.	Acres	Acres
Toxaphene	3,915	624,329	2,241	321,446	-302,883
DDT	3,584	521,786	2,645	309,118	-212,668
Parathion	2,009	113,567	3,571	161,650	48,083
Kelthane	1,803	113,952	1,281	111,449	-2,503
Carbaryl	1,216	20,816	679	22,034	1,218
2,4-D	747	116,968	784	104,797	-12,171
Malathion	1,216	87,549	980	73,219	-14,330
Phorate	69	11,108	1,082	116,912	105,804
Guthion	384	11,195	1,415	46,143	34,948
Maneb	52	2,076	158	4,506	2,430
Methyl parathion	1,083	108,440	1,686	167,468	59,028
Trifluralin	578	51,916	824	81,322	29,406
Endosulfan	1,358	157,817	1,074	89,778	-68,039
Ethion	604	36,081	1,184	67,023	30,942
Naled	1,209	65,586	1,674	83,177	17,591
Delnav	446	12,624	470	13,662	1,038
Sinox	134	12,303	427	38,508	26,205
Captan	135	1,869	242	2,872	1,003
Dylox	1,504	226,844	354	41,562	-185,282
Dimethoate	621	60,875	975	94,690	33,815
Diazinon	2,267	5,159	356	9,443	4,284
Azodrin	2,418	276,612	536	61,691	-214,921
Propanil	88	10,175	88	10,337	162
Dalapon	59	3,376	182	11,546	8,170
Dacthal	15	1,119	26	2,077	958
Simazine	453	12,493	446	12,822	329
Paraquat	631	66,375	1,017	111,002	44,627
Tetradifon	489	20,904	403	28,412	7,508
Phosphamidon	206	10,597	157	7,223	-3,374
TEPP	603	39,092	806	57,250	18,158
Diuron	120	4,858	172	10,079	5,221
Meta-Systox-R	403	5,288	458	62,144	56,856

In 1969, the San Joaquin District of the California Department of Water Resources reviewed the records of pesticide use in Kern County for the period 1948 to 1968. The records yielded information on acres treated with various pesticides, and showed the long-term trend of decreasing use of organochlorine insecticides and increasing use of organophosphorus and carbamate compounds. Figure 2.3 is taken from their report.

The dramatic decline in the use of azodrin between 1968 and 1970 is associated with its adverse effect on wildlife, and increasing restrictions on its use. This case is discussed in detail in the final chapter of the present report.

Some herbicides that made noteworthy increases in use during the two-year period are paraquat and trifluralin.

References, Chapter 2

Anonymous. 1970. Pesticide Output Turned Downward in 1969. Chem. Eng. News 48(33):15.

California Dept. of Agriculture. 1971. Pesticide Use Report 1970. Sacramento, Dept. of Agriculture.

California Dept. of Water Resources. 1969. Indications of Changes in the Manufacture, Use and Water-Borne Concentrations of Agricultural Insecticides Sacramento, Dept. of Water Resources.

Curley, A., et al., 1971. Organic Mercury Identified as the Cause of Poisoning in Humans and Hogs. Science 172:65-67.

Dunlap, L. 1971. Mercury: Anatomy of a Pollution Problem. Chem. and Eng. News 49(27):22-34.

Eyle, T. B. 1971. Alkylmercury Contamination of Foods. J. Amer. Med. Assn. 215:287-88.

Fielder, J. W. 1971. Notice of Proposed Changes in the Regulation of the California Department of Agriculture Pertaining to Economic Poisons. Sacramento, California Dept. of Agriculture.

Fowler, D. L., J. N. Mahan and H. H. Shepherd. 1971. The Pesticide Review 1970. U. S. Dept. of Agriculture. Washington, U. S. Govt. Print. Off.

U. S. Tariff Commission. 1971. United States Production and Sales of Pesticides and Related Products. Washington, U. S. Govt. Print. Off.

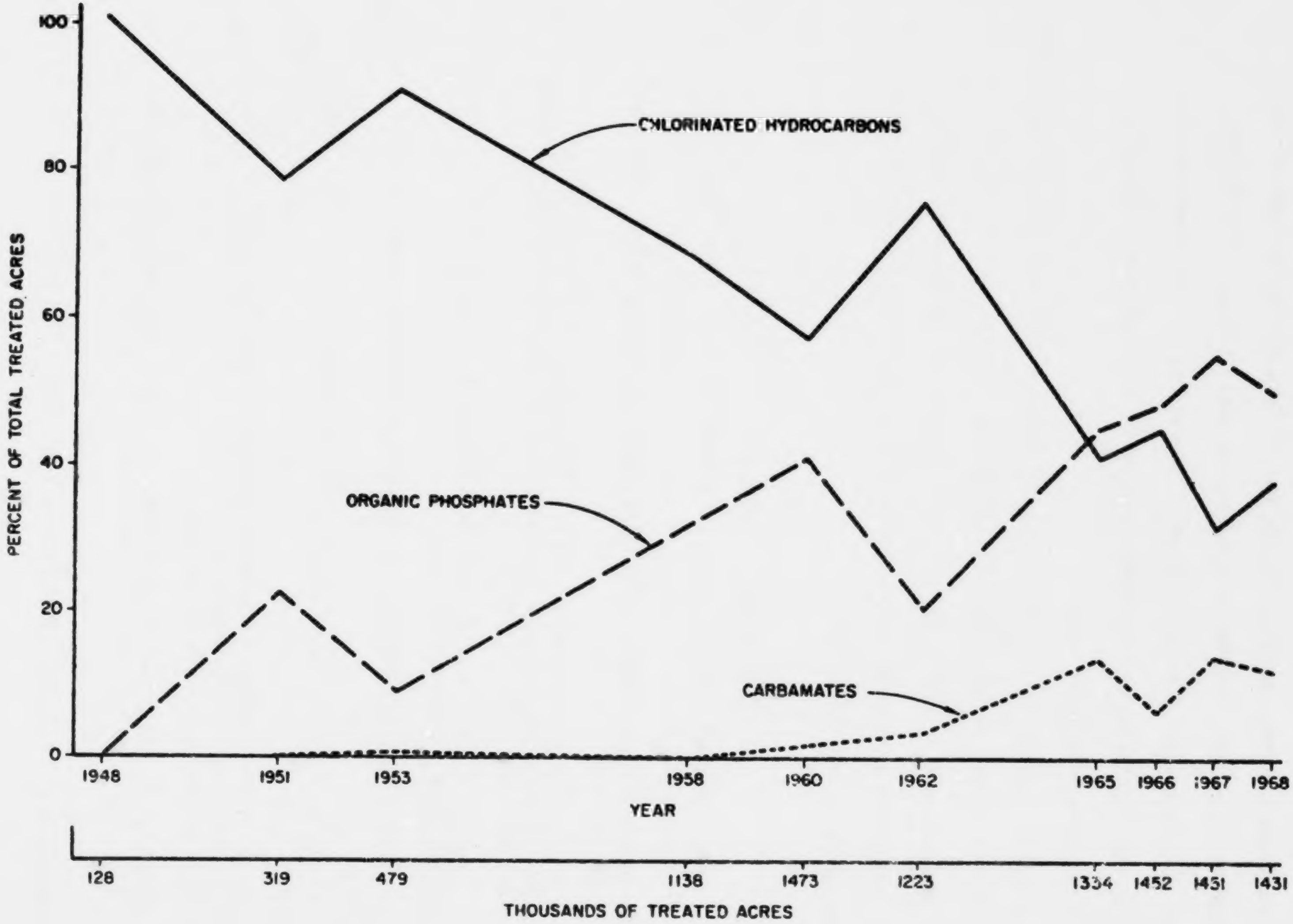


Figure 2.3 TRENDS IN THE USAGE OF SYNTHETIC INSECTICIDES WITHIN KERN COUNTY

CHAPTER 3

APPLICATION TECHNIQUES AND TYPES OF PESTICIDE MATERIAL BEING USED

Pesticides are applied in a variety of ways: from aircraft, from ground spray rigs, and by direct injection into the soil (and occasionally into water). A seemingly simple question--what percentage of pesticides is applied aerially?--needs several clarifications before it can be answered. What chemicals does one include in the category of "pesticides"? Does the question refer to the percentage of pesticide applications, apart from the quantities involved in separate applications? Or the percentage of pounds of pesticide? Or the percentage of treated area? For different purposes, different forms of the basic question are significant.

Table 3.1 shows the modes of application reported for 48 chemicals in the San Joaquin Valley in 1970. In terms of pounds applied, approximately half of this material was applied by air; in terms of acres treated, approximately two-thirds was applied by air. The major component of the "other" category in the pounds list of Table 3.1 is the fumigants: Telone, D-D mixture, methyl bromide, chloropicrin, and DBCP, which commonly include soil injection procedures (or fumigation of stored products with methyl bromide), as contrasted with the "ground" category, referring to ground spray rigs of various types.

Until 1970, the California Department of Agriculture published an annual bulletin summarizing acreages treated by licensed pest-control operators (California Dept. of Agriculture, 1970). During the years 1963 to 1969, aerial application accounted for 75.3% to 80.0% of this acreage. The percentage for the eight counties of the San Joaquin Valley, in the period July 1, 1968, to June 30, 1969, was 76.0% (5,550,233 acres applied aerially; 1,746,695 acres applied by ground). In addition to these figures for licensed pest control operators, each county agricultural commissioner had been asked to estimate the acreage treated by the growers themselves; for the eight counties, this totaled 2,567,336 acres, giving

Table 3.1 Mode of Application of Selected Pesticides in Agriculture
San Joaquin Valley, 1970

Chemical	Pounds Reported, by Mode of Application			Acres Reported, by Mode of Application		
	Aerial	Ground	Other	Aerial	Ground	Other
TOXAPHENE	1620977.69	131245.93	5518.30	443859.30	40806.10	2250.00
DDT	765732.48	100829.02	3227.76	404589.60	68932.19	2159.50
TELONE	0.00	689016.50	131476.00	0.00	6592.52	828.50
D-D MIXTURE	8.00	446798.54	308828.75	5.00	3229.97	1520.11
PARATHION	141302.93	442381.26	6089.42	220335.20	228349.44	5212.23
KELTHANE	220404.44	287546.80	2889.82	164805.05	242186.12	2232.00
METHYL BROMIDE	21.57	389879.99	31956.90	46.00	1690.47	3378.29
CARBARYL	262777.09	61250.85	2106.80	101832.08	24848.06	656.23
2,4-D	240417.79	59016.88	3818.26	341911.54	61641.78	5543.88
MALATHION	187749.53	99594.99	2297.53	170031.60	25800.89	1358.13
PHORATE	178639.07	77708.60	11521.08	182392.35	105839.10	16240.63
CHLOROPICRIN	300.00	158531.99	92719.94	60.00	1367.03	486.16
GUTHION	81604.62	162843.08	3960.27	95566.96	148260.40	2311.82
DEF-DEFOLIANT	207862.59	34553.08	405.00	149885.80	15561.25	290.00
MANEB	202548.86	39008.72	478.40	103184.51	7031.50	316.00
METHYL PARATHION	215592.56	6267.83	881.14	302522.10	9259.75	1484.00
TRIFLURALIN	872.61	210136.98	6303.53	1162.00	166027.44	1964.50
DBCP	0.00	153501.49	47690.91	0.00	11538.44	2911.05
ENDOSULFAN	171615.09	18879.45	1208.91	181223.70	19203.90	1358.50
ETHION	56321.93	129907.20	2718.18	55698.50	76480.89	1363.32
NALED	152179.13	31794.11	603.82	160779.60	33591.18	685.00
DELNAV	15319.24	127674.40	2304.84	4681.20	46249.78	630.00
SINOX	118378.52	21879.87	749.88	73230.20	12707.02	477.00
CAPTAN	52137.17	78146.45	705.60	12031.30	5740.65	327.00
DYLOX	124054.67	2740.90	478.80	107388.50	2857.50	363.00
DIMETHOATE	80630.72	36607.18	1133.17	158284.21	64516.72	1375.50
DIAZINON	32427.27	65962.37	680.50	39912.50	36802.74	358.00
AZODRIN	47018.83	48019.26	1491.01	70789.31	93932.15	2973.00
SODIUM ARSENITE	0.00	90334.26	727.52	0.00	16722.41	272.00
DISYSTON	31171.26	44101.60	8075.91	41973.50	51908.80	8203.10
PROPANIL	72722.50	2136.44	975.00	17547.00	539.60	195.00
DNBP	40530.92	34498.80	350.31	25217.30	10864.81	173.50
DALAPON	37583.82	37297.07	430.90	10741.50	12513.69	200.25
OMITE	20189.22	51637.97	406.33	15985.66	33337.82	441.75
DACTHAL	25897.45	83178.97	624.00	2993.50	5709.60	78.00
SIMAZINE	11.20	68260.23	1429.15	14.00	46905.67	723.25
CARBOPHENOTHION	14369.79	53920.49	1301.79	15649.00	63208.75	699.00
PARAQUAT	59181.26	7395.35	212.00	291415.34	18405.25	1040.00
FOLCID	45105.12	14775.78	180.00	30589.00	3464.70	30.00
TETRADIFON	45554.55	11992.94	195.22	72897.70	14336.56	394.00
PHOSPHAMIDON	29194.04	26349.45	604.40	36461.66	22248.88	757.00
TEPP	50809.14	4282.69	350.73	82854.25	9652.06	483.63
PHOSALONE	5737.42	47428.14	380.10	2688.00	21353.57	174.00
DIURON	16903.80	33299.16	478.32	7989.25	20704.28	358.00
LEAD ARSENATE STAN	0.00	44108.69	102.60	0.00	7039.10	18.00
META-SYSTOX-R	39674.61	2206.12	111.09	99691.50	7975.01	240.93
LEAD ARSENATE BAS	230.40	36677.53	510.34	10.00	4590.51	47.00
ANSAR 170	7895.31	28540.40	963.60	4330.00	12595.02	828.00
TOTAL	5727376.22	4794405.88	692594.85	4319254.27	1943121.27	76193.76

a total estimated treated acreage of 9,864,264.

The 76% applied aerially by licensed pest-control operators is somewhat higher than the percentage of aerial application derived from the data bank. However, in addition to pest-control operators' records, the data bank includes records from the growers, and application by ground rig is probably the dominant mode of application in the latter case.

In making his decision about mode of application, a grower must (consciously or unconsciously) optimize a number of parameters, including costs, urgency, area to be treated, and effectiveness. In a general way, effectiveness is associated with coverage and particle size.

The danger of environmental contamination of nontarget areas by drift is connected more closely to questions of droplet or particle size and micrometeorological conditions than to the choice between aerial and ground application (Akesson _et al._, 1970; Brazelton, 1971). Aside from the consideration of aerial versus ground application, coverage by a given quantity is related inversely to particle size. (It will be recalled that the number of spherical particles from a given volume is inversely proportional to the third power of the particle diameter.) While coverage and effectiveness increase with decreasing particle size, however, the problem of confining the pesticide to the target area also increases. For all practical purposes under field conditions, particles below 50 microns in diameter are aerosols, and although these small particles are extremely effective as adulticides and have a remarkable immediate effect on pest populations, they do not settle out of their own accord but probably remain airborne until they undergo photochemical decomposition or are carried to earth by rain or dust. On the other hand, particle sizes much above 500 microns are not practical from the point of view of coverage, except where the pesticide will be translocated and is effective as a systemic poison, or where the material must be rigorously confined to the target area because of its high toxicity to man or to other desired species in the vicinity of the target area. In the wide range between 50 and 500 microns, finer sprays may be used where the material has low toxicity to nontarget organisms and where low doses are applied over large areas. Medium sprays in the range of 250 to 300 microns are used for ordinary spraying, and the coarser sprays for more highly toxic materials. In aerial application, droplet size is regulated by modification of nozzle size and shape, mode of operation, pressure, and direction in relation to the jet stream. In ground spray rigs, the pesticide may be applied under hydraulic pressure from booms and nozzles or by blower types.

The picture is further complicated by the facts that application equipment invariably produces a range of droplet sizes, and that droplet size decreases while the pesticide or its solvent is evaporating.

Next to droplet size, the most important factor influencing drift is the climate in the immediate locality of application. In practice, spraying by ground or aerial application is not recommended when winds reach 10 miles per hour or in periods of temperature inversion or in generally turbulent weather. To a limited extent, adverse weather is more tolerable when the hazard or likelihood of drift is reduced by the nature of the material (lower toxicity to nontarget species) or by a larger droplet size.

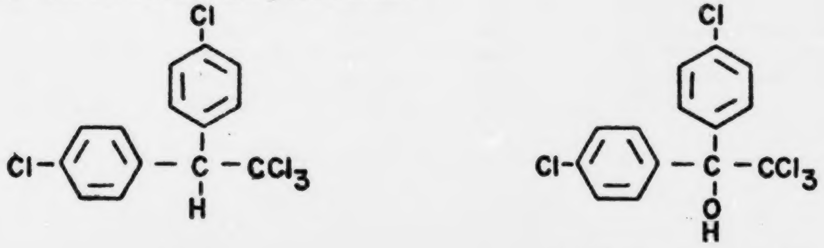
Only after these factors are taken into consideration is it meaningful to generalize that the likelihood of drift of applied pesticides increases in the following order: soil injection < hydraulic ground spray < air-carrier ground spray < aircraft.

Generally, the active pesticide material is applied in a "formulation" (Leach, 1966). For example, it may be dissolved in a water-insoluble solvent, with emulsifier added so that, when the material is diluted with water prior to application, it will form an emulsion. This formulation is called an emulsifiable concentrate. Another common formulation is wettable powder, with the pesticide material adsorbed on inert material and wetting and dispersing agents added. Before application, the wettable powder is diluted with water, forming a suspension. A given pesticide tends to persist longer on leaf surfaces when applied as a wettable powder than when applied as an emulsifiable concentrate. The dust type of formulation ordinarily comes in a ready-to-use form, already diluted to a few percent of active ingredients absorbed on finely divided solid particles.

The pesticide use reports include information about the formulation type. Found in addition to the types mentioned above are pellets, granules, sprays, liquids, etc. There is a degree of ambiguity among the formulation types reported. For example, emulsifiable concentrates are sometimes reported as liquids. However, Table 3.2 provides some insight into the forms in which the 48 pesticides were used.

The quantities reported in the preceding tables have been sumarized for a twelve-month period. However, the pesticide use reports include the date of application. Thus, it is possible to examine the pesticide use pattern during the twelve-month period, as shown in Figures 3.1-3.4.

Figure 3.1 shows the quantities of three organochlorine compounds--toxaphene, DDT, and kelthane (dicofol)--used in agriculture in each month of 1970 in all eight counties of the San Joaquin Valley. The use of all three pesticides is most concentrated in May-September. A combination of the first two is commonly applied as an insecticide on cotton, and their heaviest use is in the more southern of the eight counties. Kelthane, a miticide, is chemically related to DDT (Figure 3.5) but is much less persistent.



DDT

Kelthane or Dicofol

Figure 3.5 Two Organochlorine Pesticides

Table 3.2 Formulation-Types of Selected Chemicals
San Joaquin Valley, 1970

Chemical	Pounds Reported, by Formulation					
	Wettable Powder	Dust	Other "Dry"	Emulsifiable Concentrate	"Liquid"	Other "Wet"
Toxaphene	90.00	529.80	16.00	597,423.98	1,150,681.14	17,001.00
DDT	30,430.58	92.90	190.45	275,738.85	556,199.56	7,138.47
Telone	0.00	0.00	0.00	330,453.75	482,250.25	7,788.80
D-D Mixture	13,801.92	0.00	0.00	72,790.00	656,582.76	12,556.60
Parathion	332,297.04	1,658.63	11,124.77	120,966.67	125,121.90	7,372.84
Kelthane	20,264.76	28,127.32	486.30	141,113.31	319,011.71	1,837.66
Methyl Bromide	332,773.70	32,480.10	71,510.08	21.57	220.68	0.00
Carbaryl	99,339.50	198,971.11	13,021.95	2,633.29	12,169.48	16.13
2, 4-D	4,115.89	0.00	460.46	84,756.11	208,226.66	5,693.81
Malathion	86,027.51	7,123.30	408.27	93.932.76	101,045.19	1,059.82
Phorate	3,842.69	1,395.63	179,156.89	38,420.22	46,313.93	445.09
Chloropicrin	182,834.28	662.40	23,281.87	0.00	44,834.76	0.00
Guthion	14,381.70	1,239.61	217.00	87,994.59	141,368.59	3,206.47
Def-Defoliant	0.00	0.00	0.00	104,373.40	138,306.27	141.00
Maneb	196,433.78	18,050.84	8,824.33	3,705.76	15,052.07	0.00
Methyl Parathion	3,538.60	0.00	741.92	128,321.96	86,994.22	3,676.75
Trifluralin	851.34	0.00	38.32	171,730.36	43,914.16	858.94
DBCP	0.00	0.00	0.00	95,772.88	103,979.52	1,440.00
Endosulfan	9,373.86	14,088.26	7,261.67	71,962.30	86,477.07	2,540.30
Ethion	36,855.02	9,362.64	0.00	65,417.14	75,202.14	2,110.37
Naled	773.66	40,060.38	18.00	40,659.04	102,188.75	937.24
Delnav	245.78	0.00	0.00	47,950.33	95,882.69	1,219.68
Sinox	73.60	0.00	0.00	27,937.62	111,960.54	1,027.50
Captan	14,591.14	51,570.91	50.00	64.00	64,678.18	35.00
Dylox	122,021.70	76.00	4,166.15	178.27	832.25	0.00
Dimethoate	1.91	0.00	0.00	38,629.07	78,175.27	1,564.83
Diazinon	62,581.20	4,370.68	2,278.13	11,593.13	18,147.53	99.50
Azodrin	0.00	0.00	0.00	33,820.91	62,620.69	87.50
Sodium Arsenite	48.00	0.00	72.00	16,153.54	73,644.56	1,143.68
Disyston	1,047.78	609.27	53,500.83	15,510.16	12,634.72	46.01
Propanil	0.00	0.00	0.00	58,225.12	17,608.82	0.00
DNBP	0.00	0.00	0.00	10,200.44	65,179.39	0.00
Dalapon	70,003.73	40.70	4,726.00	332.84	208.52	0.00
Omite	45,698.66	768.00	151.65	8,939.41	16,627.80	48.00
Dacthal	62,775.08	0.00	5,721.40	0.00	1,403.94	0.00
Simazine	69,106.67	0.00	1,034.41	364.80	0.19	0.00
Carbophenothion	4,939.87	2,584.91	0.00	21,547.12	40,288.43	251.74
Paraquat	102.78	0.00	0.00	24,240.25	42,284.91	160.67
Folcid	0.00	0.00	0.00	9,553.92	47,644.73	2,862.25
Tetradifon	4,045.97	661.30	1.36	27,629.01	25,032.08	373.00
Phosphamidon	342.00	0.00	0.00	19,471.26	35,151.00	1,243.63
Tepp	100.55	6,506.52	0.01	22,745.74	25,802.25	287.50
Phosalone	0.00	0.00	0.00	31,740.13	21,805.53	0.00
Diuron	47,543.68	240.00	4,150.40	0.00	0.00	0.00
Lead Arsenate Stan	43,261.34	0.00	949.95	0.00	0.00	0.00
Meta-Systox-R	97.50	0.00	0.00	15,756.47	25,175.47	962.33
Lead Arsenate Bas	33,920.56	0.00	2,960.11	0.00	537.60	0.00
Ansar 170	0.00	0.00	0.00	10,981.96	26,417.36	0.00

FIGURE 3.1

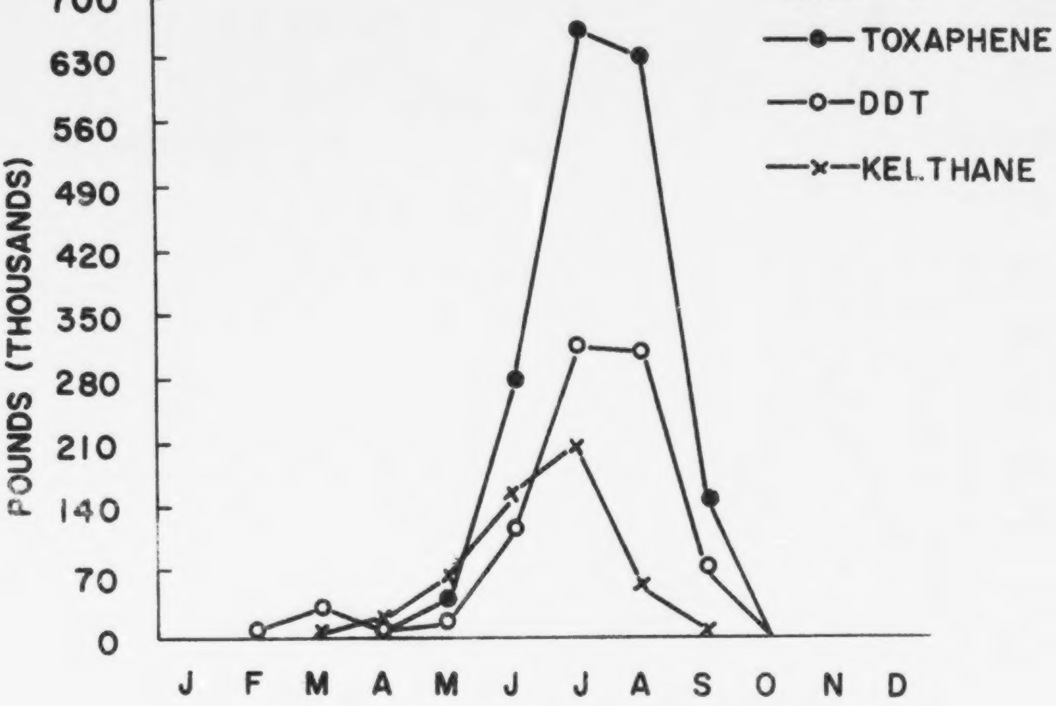
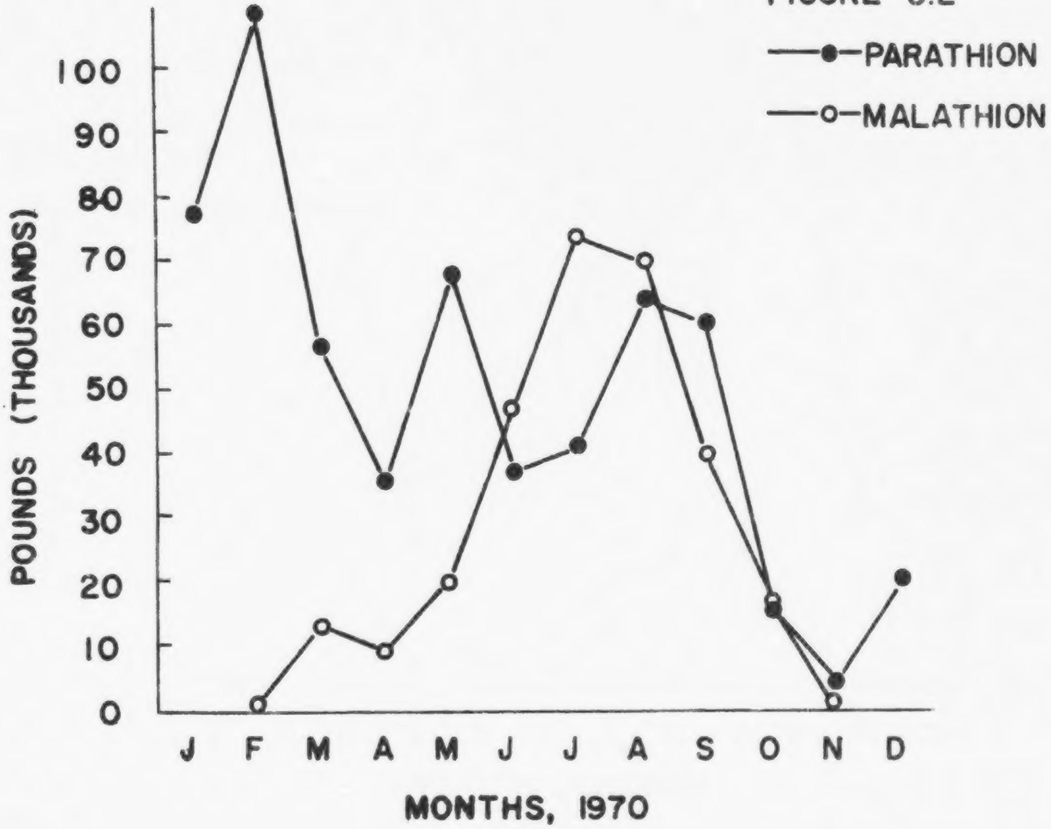


FIGURE 3.2



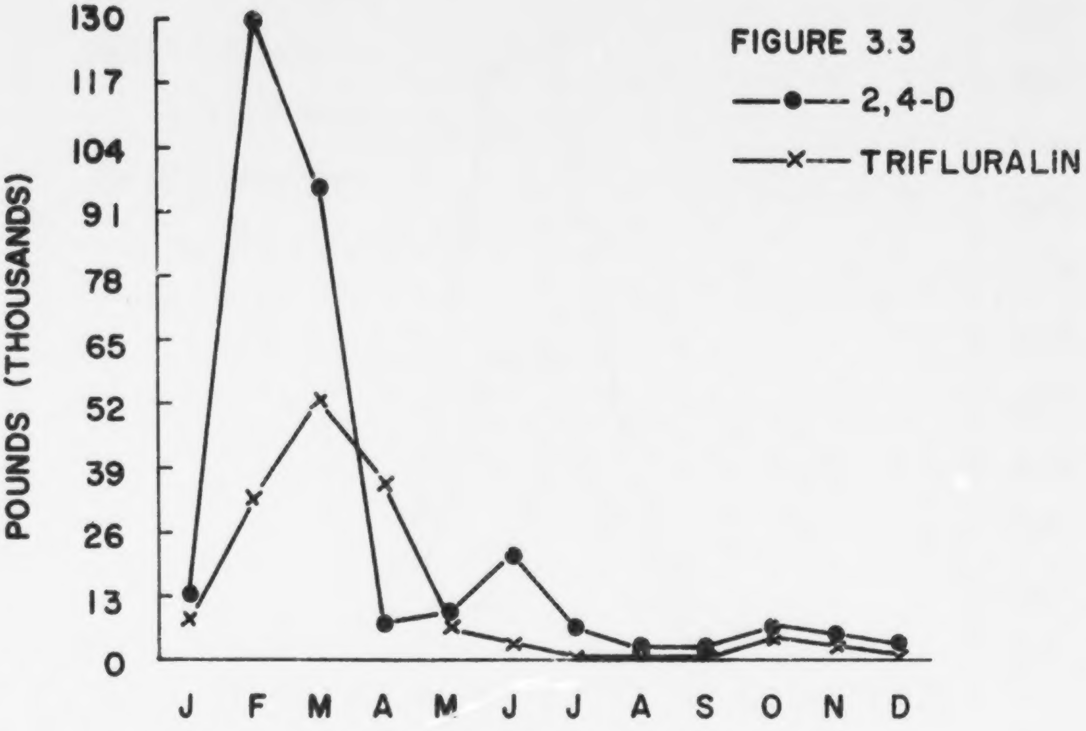


FIGURE 3.3

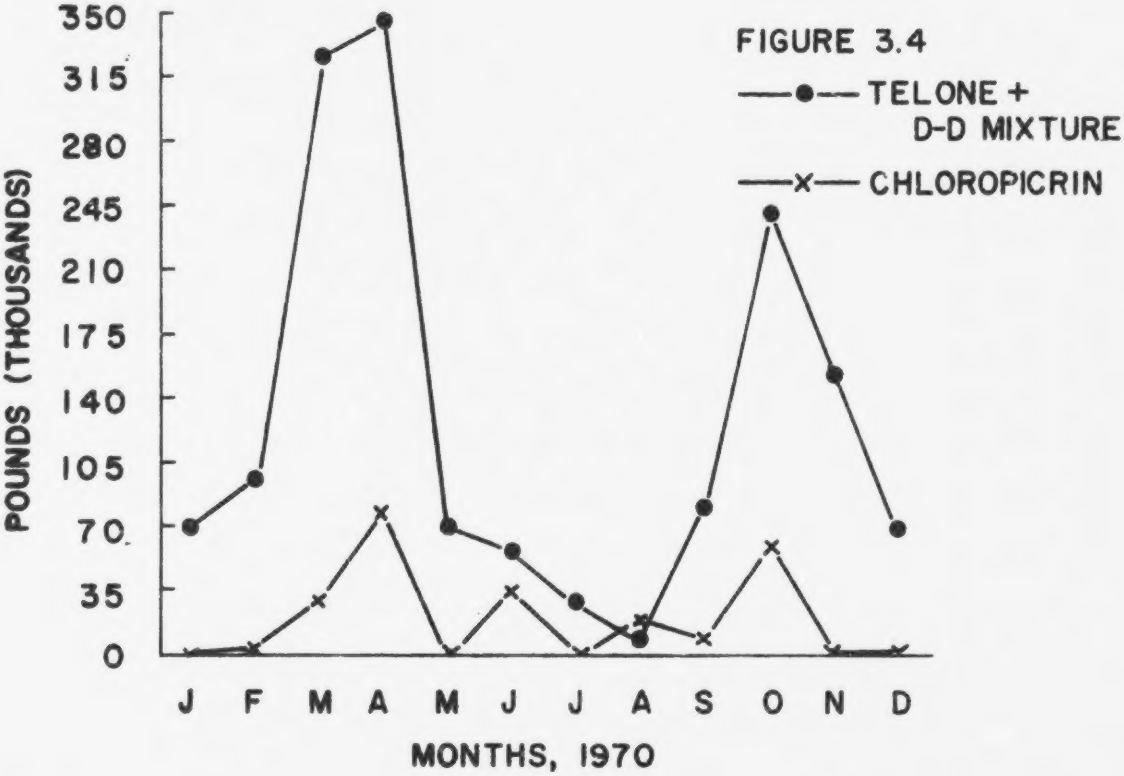


FIGURE 3.4

Figure 3.2 shows monthly use in the eight counties of the two top organophosphorus insecticides, ethyl parathion and malathion. Malathion use reaches a peak in the summer months, and has a longer period of heavy use than do the organochlorine compounds of Figure 3.1. Malathion is used in large quantities on citrus, particularly oranges, which tends to extend the use into September and October. The use pattern of parathion has several peaks, reflecting the wide variety of crops and insect pests on which it is used. A big user is peaches, and the drop in use in June and July is attributable partly to the interval required between application and the entry of harvesters into peach orchards, in July and August. Parathion is noted for high acute toxicity to man and other mammals, while malathion, being much less toxic, is used extensively in residential pest control (see Table 2.1). Such use is not included in Figure 3.2, which shows only agricultural uses.

Figure 3.3 shows, in contrast to insecticides, the use of two herbicides in agriculture in the San Joaquin Valley in 1970. Use of herbicides in weed control is concentrated in the early months to eliminate undesirable plants before they establish themselves as competitors for space, water, and nutrients (U.S. Agricultural Research Service, 1969). Herbicide hazards to desirable plants (crops) from application in summer impose additional limitations on their use beyond the early spring.

Figure 3.4 shows the application of some soil fumigants by months. Telone and D-D mixture, being similar substances, are combined in this diagram. Being commonly applied by direct injection into the soil for control of root nematodes (Lyndall and Mather, 1971), they are not generally applied during the growing season. The times of high use are in the spring and postharvest periods.

Graphs of this type prompt several questions and speculations. The principal compartments of the environment in which most pesticides are degraded to nontoxic materials are the atmosphere and the soil. In the atmosphere, the dominant degradative process is presumably photochemical (Crosby, 1969). The use of many of these materials is concentrated in the months of intense sunlight (Figures 3.1 and 3.2), reducing their ability to persist in the environment, although the well-known persistence of DDT (or its derivative, DDE) in the lipids of biota can be explained by its heavy use over a period of many years, and its biological concentration through food chains. This latter phenomenon is noted in the food chain of the various trophic levels of aquatic biota to fish-eating birds to other predatory birds; it is also observed in terrestrial biota up to terminal carnivores, including man.

A practical consequence of this natural phenomenon is the long-standing ban on the use of DDT on alfalfa grown for hay, to prevent the buildup of excessive levels of DDT and metabolites in meat and milk from cattle fed the hay. Even so, a large portion of the DDT used in the San Joaquin Valley in 1970 was on alfalfa grown for seed.

Compared with insecticides, a larger proportion of applied herbicides and soil fumigants reach the soil. The reason is the time of year in which they are applied (low crop cover) and the mode of their application. The dynamics of soil systems are thus of considerable interest. In addition to degradation by soil microorganisms and by hydrolysis, the less reactive pesticidal materials can persist in soil by adsorption, and by absorption and storage within the cells of soil organisms (Kearney, Nash and Isensee, 1969). For the more volatile materials, vaporization and escape into the atmosphere is significant, and for more soluble materials, leaching by percolating water is possible. (In regions of high rainfall or excessive irrigation, or in regions of unstable soil susceptible to erosion, a mode of undesirable pesticide dispersal is the transport of pesticides adsorbed on soil particles. These conditions are not very common in the San Joaquin Valley, however.)

In addition to questions about the ultimate fate of pesticides in the environment, prompted by Figures 3.1-3.4, there is also the uncertainty of hazards that combinations of pesticides may give rise through "potentiation"--an increase in 'killing power' beyond that expected from a mere summation of the constituents. This phenomenon is sometimes exploited for the grower's advantage. Potentiation may have many causes. In one mechanism, for example, one of the chemicals may deactivate an enzyme system of the target organism that ordinarily detoxifies the other chemical (by hydrolysis, oxidation, etc.), thus vastly increasing the susceptibility of the organism to intoxication by the pesticide that it ordinarily detoxifies.

The point, here, is that organisms (including man and other nontarget organisms) are exposed unintentionally to combinations of pesticides, and some of these combinations might have unpredictably high toxicity. For example, the relatively low mammalian toxicity of malathion is generally attributed to the ability of mammals to hydrolyze the compound before it exerts its toxic action. During the months of high usage, however, a mammal might conceivably be exposed also to another material that would deactivate the hydrolytic enzyme system that protects it from malathion.

Although Figures 3.1 to 3.4 were composed from tabulated data, for the present study it was convenient to obtain similar information directly from the computer in the form of histograms. With this program, it was possible to derive the use pattern for any specified chemical against any specified pest or group of pests on any specified crop or group of crops, in any county or group of counties in the San Joaquin Valley. Figure 3.6 is an example of such a histogram.

References, Chapter 3

Akesson, N. B., W. E. Yates and S. E. Wilce. 1970. Controlling Spray Atomization. Agrichem. Age. 13:10-17.

Brazelton, R. W. 1971. Control of Chemical Drift. Berkeley, California. U. C. Agri. Ext. Serv. Bull. No. 5.

California Dept. of Agriculture. 1970. Field Crops and Agricultural Chemicals; Acreages Treated for Agricultural Pest Control, by Counties, July 1968 through June, 1969. Sacramento, California Dept. of Agriculture. (Issued March 16, 1970).

Crosby, D. G. 1969. The Nonmetabolic Decomposition of Pesticides. Annals. N. Y. Acad. Sci. 160:82.

Kearney, P. C., R. G. Nash, and A. R. Isensee. 1969. Persistence of Pesticide Residues in Soils. In: Chemical Fallout. Edited by M. W. Miller and G. G. Berg. Springfield, Ill., Thomas, p. 54-67.

Leach, S. S. 1966. Pesticide Formulations; How to Calculate Dosage and Mix Pesticides. In: Pesticide Information Manual. Edited by the Northeastern Regional Pesticide Coordinators. Durham, New Hampshire, University of New Hampshire, p. C5-C16.

Lyndall, R. C. and S. M. Mather. 1971. The Nematode Study Committee and California's Nursery Nematode Control Program. Down to Earth. 27:12-17.

U. S. Agricultural Research Service. 1969. Suggested Guide for Weed Control. Washington, U. S. Govt. Print. Off. (U. S. Agr. Res. Serv. Handbook, No. 332).

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177069.15    1                          **
             1                          **
160668.95    1                          **  **
             1                          **  **
147669.85    1                          ******
137620.95    1                        ********
             1                        ********
             1                        ********
             1                        ********
             1                        ********
             1                        ********
             1                        ********
             1                        ********
 73231.47    1                        **********
 72618.97    1                      ************
             1                      ************
             1                      ************
 45590.72    1                    **************
             1                    **************
             1                    **************
 25457.59    1        **          **************
 12984.40    1        **        ****************
  7412.61    1        ****      ****************
   129.69    1************************************************
             1---1---1---1---1---1---1---1---1---1---1---1---1
              JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

END HISTO 6 MIN, 11.3 SEC.
```

Figure 3.6 Total pounds of DDT applied on cotton in the San Joaquin Valley by month

1970

CHAPTER 4

ROUTES OF PESTICIDE ENTRY INTO THE AQUATIC ENVIRONMENT

The routes of pesticide entry into the water environment have been discussed in many review articles (Nicholson, 1970; Nicholson and Hill, 1970; U. S. Dept. of HEW, 1969; Foy and Bingham, 1969; Westlake and Gunther, 1966; West, 1966). This section presents first, under each route, a general review of the route, and then discusses the applicability of each route to the San Joaquin Valley.

Figure 4.1 shows the cycling of pesticides in the environment and the various routes by which they may enter the water environment. These routes can be classified as:

1) Runoff and sediment transport
2) Subsurface drainage
3) Direct application
4) Atomospheric transport
5) Industrial wastes
6) Municipal wastes
7) Agricultural wastes
8) Accidents and spills

Runoff and Sediment Transport

Runoff is generally considered to be the major route of pesticide movement into the water environment (Nicholson, 1970; Nicholson and Hill, 1970; U. S. Dept. of HEW, 1969; Bailey, 1966). Edwards et al. (1970) reported that runoff water and surface runoff are more important routes than leaching in transport of dieldrin from soil into ponds. Nicholson and co-workers have done intensive studies on the routes of pesticide movement into the water environment, and

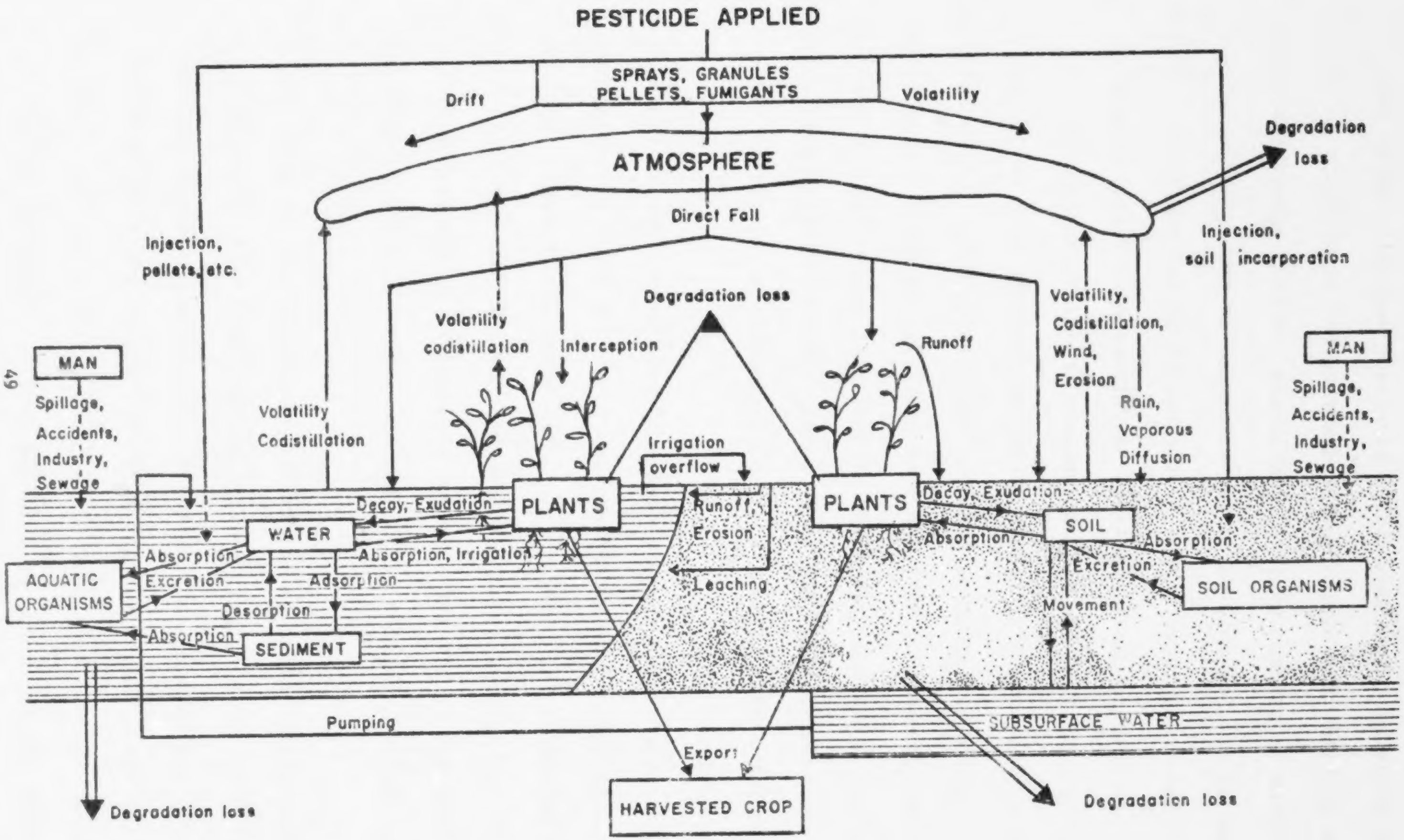
PESTICIDE APPLIED
SPRAYS, GRANULES
PELLETS, FUMIGANTS
Drift
Volatility
ATMOSPHERE
Degradation loss
Direct Fall
Injection, pellets, etc.
Injection, soil incorporation
Degradation loss
Volatility codistillation
Interception
Runoff
Volatility, Codistillation, Wind, Erosion
Rain, Vaporous Diffusion
MAN
Spillage, Accidents, Industry, Sewage
Volatility Codistillation
Irrigation overflow
MAN
Spillage, Accidents, Industry, Sewage
PLANTS
PLANTS
Decay, Exudation
Decay, Exudation
WATER
Runoff, Erosion
SOIL
Absorption
Absorption
Absorption
Absorption, Irrigation
Excretion
AQUATIC ORGANISMS
Excretion
Adsorption
Leaching
SOIL ORGANISMS
Desorption
Movement
Absorption
SEDIMENT
Pumping
SUBSURFACE WATER
Export
Degradation loss
HARVESTED CROP
Degradation loss

Figure 4.1 Pesticide Cycling in the Environment

in their two recent articles (Nicholson, 1970; Nicholson and Hill, 1970) they specified runoff as probably the single most widespread and significant source of low-level contamination of surface water by pesticides. During runoff the pesticide may be adsorbed on eroding soil particles suspended in the runoff water, or both. Factors influencing runoff are: 1) the nature of the pesticide; 2) the extent of its use; 3) edaphic considerations; 4) climatic factors; 5) topography; and 6) practices in land use and management. Pesticides with short persistence time naturally have less runoff potential than the more persistent pesticides. Chlorinated hydrocarbon pesticides, because of their low solubilities in water, are probably transported with the soil particles in the adsorbed state rather than in solution. Lichtenstein (1958) showed that soils that are high in humus will yield less insecticides than sandy soils. Heavy rainfall immediately after application of pesticides will have a high potential for pesticide transport into the water environment.

Most studies focusing on runoff have been conducted where rainfall is high and land is sloped. In such areas an unexpected heavy rain after pesticide application can wash pesticide from the soil into the water environment. The San Joaquin Valley, however, is relatively flat and has low rainfall (about 15 inches or less annually). Hence, runoff there is not expected to be the real problem as it is in the northeastern section of the country, where rainfall is high and land is hilly.

Even so, the irrigation of crops in the San Joaquin Valley can give rise to pesticide runoff in some cases. In flood irrigation, where water is applied at one side of the field and allowed to flow to the other side, it never reaches the other side at the same time in all checks. When excess water accumulates at the end of a check, farmers sometimes allow it to overflow into the drainage system where pesticide may be transported in the runoff. Sprinkler or furrow irrigation has no such potential.

Runoff potential is prevalent in areas adjacent to the San Joaquin Valley, such as the Sacramento delta region, where rice cultivation is intense. Swift (1966) reported fish losses directly attributable to runoff water from the rice fields that contaminated drain ditches and other waterways. He pointed out that these losses occurred because some farmers did not follow directions for the use of dieldrin under such practices. The directions were that the water from the rice fields should not be allowed to runoff for at least 10 days, to allow most of the dieldrin to settle to the bottom, along with sediments, during the waiting period.

A recent study of watershed management in the California region (California Dept. of Water Resources, 1970) found that erosion activity in most of the regions of the San Joaquin Valley was "none to moderate." Erosion was severe only in very small areas in the western part of the valley. The reason may be that agricultural developments are new there. Sediment yield values in California were reported to be lowest in the San Joaquin Valley.

West (1966) reported that the greatest source of pesticides reaching waters in California was runoff from agricultural land. Data are insufficient to determine whether that finding can be applied to the San Joaquin Valley.

Experts interviewed differed as to the importance of pesticide movement with runoff and the transport of sediments. A study on this aspect is planned by the River Basin Planning Group in the U. S. Department of Agriculture.

Scientists at the Southeast Water Laboratory are working to develop means of predicting runoff pollution and preventing it (Nicholson, 1970). Being considered as the basis for a new formula for predicting pesticide loss from the soil is the Universal Soil Loss Equation, developed by soil conservationists to guide conservation farm planning throughout the U. S. According to Nicholson (1970), recommended chemicals and practices would be used after this equation predicts what to anticipate. In the Soil Loss Equation, A = RKLSCP, where A is the computed soil loss in tons per acre, R is the rainfall factor, K is the erodability factor, L is the effect of slope length, S is the effect of slope gradient, C is the crop-management factor, and P is the erosion-control practice factor. Applicability of the equation to erosion problems was discussed by Johnson and Moldenhauer (1970).

Subsurface Drainage

Bailey (1966) reported that, barring accidental contamination, biocides from agriculture enter surface water courses from two principal sources: 1) subsurface drainage; and 2) overland flow drainage. Other investigations (California Department of Water Resources, 1968; Johnston *et al.*, 1967) showed that only a small proportion of the pesticides applied to a field were found in tile drainage. The U. S. Department of Health, Education and Welfare (1969) indicated that ground-water sources, the same as rainfall, make only a minute contribution of pesticides to a surface water such as a perennial stream. Most reported results show very little downward movement of pesticides in the soil. Swobada and Thomas (1968) showed that, under normal rainfall, parathion was very unlikely to contaminate underground water supplies by leaching. Aksenov *et al*. (1970), from studying 2,4-D amine salts, concluded that 2,4-D is not unlikely to reach ground-water levels. Grasso *et al*. (1968) found neither chlorinated hydrocarbons nor organophosphate insecticides in underground waters from various Italian regions. Leh (1968) studied the vertical movement of several herbicides in soil columns and concluded that ground water is not likely to become contaminated under normal agricultural practice. Lichtenstein (1970) reported in a review article that commonly used insecticides appear unlikely to move through soils with water. Hindin (1970) concluded from a literature review that about 90 percent of the recoverable DDT residue will reside in the top three inches of the soil (cultivation or plow depths). The main factors influencing the vertical predicts what to anticipate. In the Soil Loss Equation, A = RKLSCP, where A is the computed soil loss in tons per acre, R is the rainfall factor, K is the erodability factor, L is the effect of slope length, S is the effect of slope gradient, C is the crop-management factor, and P is the erosion-control practice factor. Applicability of the equation to erosion problems was discussed by Johnson and Moldenhauer (1970).

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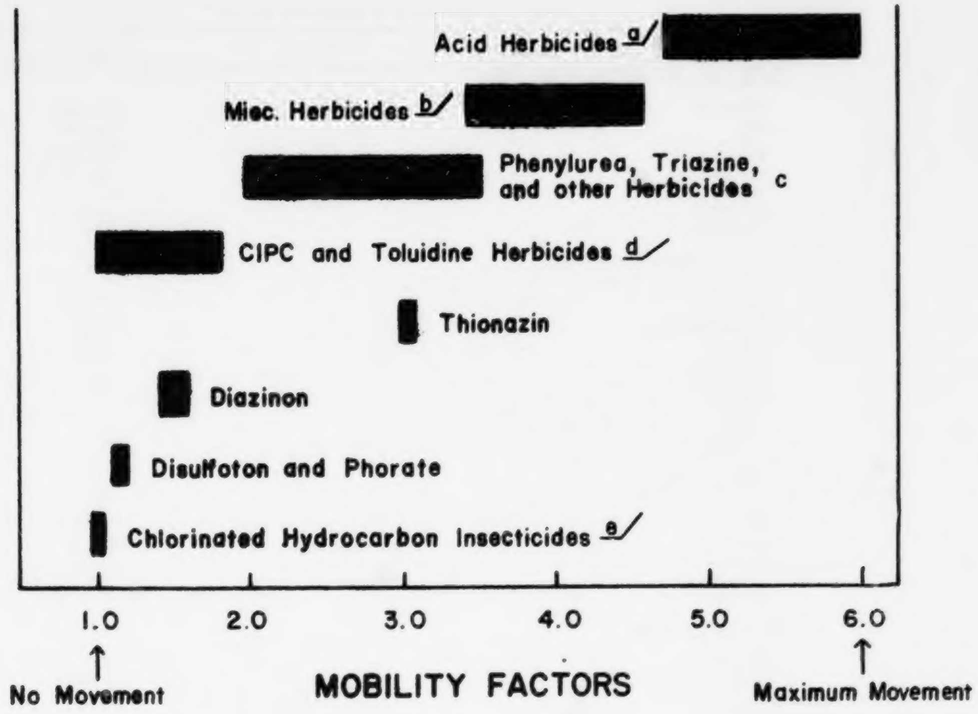

Figure 4.2 Relative mobilities of pesticides in a subirrigated column system (Harris, 1967; Harris, 1968)

a Includes dicamba, tricamba, 2,3,6-TBA, amiben, methoxyfenac, and fenac.

b Includes DNBP, pyrichlor, 7175, norea, and cycluron.

c Includes monuron, buturon, linuron, diuron, atrazine, simazine, propazine, prometryne, EPTC, pebulate, vernolate, and diphenamid.

d Includes benefin, planavin, CIPC, trifluralin, and dipropalin.

e Includes aldrin, o,p'-DDT, DDE, dieldrin, endrin, and heptachlor.

Table 4.1 Solubility of Pesticides in Water[a]

Pesticide and its degradation products	Solubility (ppm)
Chlorinated hydrocarbon insecticides	
Chlordane	Insoluble
DDD	Insoluble
DDT	0.001; 1
Endosulfan	Insoluble
Kelthane	Insoluble
Methoxychlor	0.1
Perthane	Insoluble
Toxaphene	0.4; 3
Organophosphorus insecticides	
Azodrin	Soluble
Baytex	54, 56
Carbophenothion	0.34
Delnav	Insoluble
Diazinon	40
Dimethoate	20,000; 30,000
Disyston	66
Dylox	120,000; 150,000
Ethion[b]	2
Guthion	33
Malathion	145
Meta Systox R	Soluble
Methyl parathion[c]	50
Naled	Insoluble
Paraoxon	2,400
Parathion	20; 25
Phorate	50; 85
Phosphamidon	Very soluble
Systox	666; 2000
Other insecticides	
Carbaryl	40
Lead arsenate, dibasic	Insoluble
Herbicides	
Amitrole	Very soluble
Ansar 138[d]	Very soluble
Ansar 170[d]	Very soluble
Atrazine	70
Copper sulfate pentahydrate	240,000
2,4-D	500; 900
2,4-D sodium salt	30,000; 45,000
Dacthal	<0.5
Dalapon sodium salt	900,000
Def Defoliant	Insoluble
Diuron	40; 42
DNBP	50; 1000
Magnesium chlorate	Very soluble
MCPA	1174; 1600
Paraquat	Very soluble
Propanil	225; 500
Pyrazon	
Simazine	Soluble
Sodium arsenite	Soluble
Sodium chlorate	500,000
Sodium TCA	Very soluble
Sutan[d]	45
Tillam	92
Trifluralin	24
Other pesticides	
Captan (fungicide)	Insoluble
Chloropicrin (fumigant)	2,000
DBCP (fumigant)	1,000
D-D mixture (fumigant)	Insoluble, 2,800
Ethylene dibromide (fumigant)	4,300
Maneb (fungicide)	Few ppm
Methyl bromide (fumigant)	13,400
Omite (acaracide)[e]	Very low solubility
Ziram (fungicide)	65

[a] Except where indicated otherwise, all the data are from: Gunther, F.A., W.E. Westlake, and P.S. Jaglan (1968). Reported solubilities of 738 pesticide chemicals in water. Res. Rev. 20: 1-148. As far as possible the solubilities reported are at close to 25° C.

[b] Niagara Chemical Division. 1971. Insecticide - Miticide.

[c] Mitchell, L.E. (1966). Pesticides: properties and prognosis. Adv. Chem. Series 60: 1-22.

[d] Weed Science Society of America (1970). Herbicide Handbook, WSSA Monograph 3, p.368.

[e] United States Rubber Company Chemical Division. Agricultural Chemicals.

movement of pesticides are the type of pesticide, its solubility, its formulation, the soil type, climate, and the microbial population. Bailey and White (1969) discussed many of these factors in a review article. It is generally believed that the tendency for pesticides to move through soil increases from finer-textured soil to coarse-textured soil. This trend is supported by twenty-one references cited by Bailey and White (1969). The lower tendency of movement in finer-textured soils is due mainly to the higher adsorption of pesticides in such soils. The rate of downward movement has been shown to be related inversely to adsorption (Harris, 1966; McCarty and King, 1966; Perry). Another property determining movement is solubility. The more soluble a pesticide, the faster it moves downward in soils. Gray and Weierich (1968) correlated the depth of leaching of five thiocarbamate herbicides with their solubilities in water. Ashton (1961) showed that the relative movement of four substituted ureas were related directly to their water solubilities. Table 4.1 shows the water solubilities of selected pesticides used in the San Joaquin Valley. The least soluble of these are the chlorinated hydrocarbons, and their downward movement in soils reflects this fact (Figure 4.2). Sometimes, however, the rate of movement of a pesticide may differ from the one expected from its solubility in water. Thus, DDT can be solubilized by humic acid fractions and can move readily in soils (Ballard, 1971).

Its persistence also determines whether a pesticide would contaminate subsurface water. Even moving very slowly in the soil, a highly persistent pesticide may eventually reach underground water, whereas less persistent pesticides may first dissipate by degradation or other processes. An example was cited by Beran and Guth (1965), who studied the movement of lindane, DDT, parathion, and aldrin in several soil types. Only lindane in a sandy soil reached the ground water. Its relatively high solubility and high persistence made that possible.

The main climatic factor affecting pesticide movement is rainfall. Other things being equal, the more and oftener that water (rainfall or irrigation) is applied, the greater is pesticide movement. Movements determined for pesticides in soils are difficult to compare under a common scale because most studies have been carried out under different environmental and soil conditions. Only two studies examined the movement of several pesticides under the same conditions. These are reported in Figure 4.2 and Table 4.2. Figure 4.2 shows the relative mobilities of pesticides in a subirrigated soil column. It can be seen that the mobilities vary from 'no movement,' for chlorinated hydrocarbon insecticides, to 'maximum movement,' for some of the benzoic acid herbicides. Table 4.2 arranges in decreasing order the mobilities of 16 herbicides as determined by soil thin-layer chromatography. Here again, acidic herbicides are among the most mobile.

Since the downward movement of pesticides depends mainly on soil characteristics, the soils in the valley must be considered before such movement can be discussed. The soils of this study area were discussed by Storie (1951).

The soils in the San Joaquin Valley are called valley soils formed on alluvium from upland terraces. These particular soils include recent alluvial fans, shallow soils over hardpan, and the basin soils. Saline and alkali soils are present in various parts of the valley. The general texture of the soils is loam, although in the central part of the valley the soils are mostly clay. Because of the finer texture of clay soils and the occurence of hardpans and alkalinity, it is improbable that pesticides move downward and contaminate ground water there.

The eastern side of the valley has coarser-textured soils than the western side, and the hardpans are sometimes present. Two localized areas in the eastern side have wind-modified sandy soils. The site where pesticide is most likely to move downward to underground water is these localized and isolated wind-

Table 4.2 Herbicide Mobility as Measured by Soil-thin-layer Chromatography[1]

Herbicide	*R_F Value on		
	Chillum Silt Loam	Hagerstown Silty Clay Loam	Lakeland Sandy Loam
Dicamba	0.96	0.96	1.00
Amiben	.87	.91	1.00
Fenac	.62	.84	1.00
MCPA	.62	.78	1.00
2,4-D	.50	.69	1.00
Dephenamid	.39	.49	0.94
Monuron	.44	.48	.89
Atrazine	.35	.47	.89
Simazine	.41	.45	.96
Propazine	.24	.41	.77
Diuron	.23	.24	.60
Prometryne	.08	.25	.37
CIPC	.13	.18	.59
Diquat	.04	.06	.19
Paraquat	.00	.00	.13
Trifluralin	.00	.00	.00

[1] Helling and Turner, 1968.

*R_F value is a quantitative indication of the front of herbicide movement.

modified sandy soils.

In considering contamination of underground water, the depth of water tables should also be considered. If the water table is very deep, it is less likely that pesticides move to the underground water.

Pesticides may reach the subsurface drainage system instead of percolating further down into the underground water. Johnston et al. (1967) studied the movement into open drains and tile drains of pesticides applied to soils of the San Joaquin Valley. The quantities of chlorinated hydrocarbon residues they found were only relatively small in tile drainage effluents, and higher in effluents from open drains that collected both surface and subsurface drainage waters. When the concentration factor of the water percolating through the soil was considered, the total quantity of residue in the tile drainage effluent did not exceed--and is generally less than--the total quantity of residue applied in the irrigation water.

The California Department of Water Resources (1968) studied the fate of DDT and lindane applied to a 110-acre plot in Western Fresno (San Joaquin Valley). The researchers concluded that tile drain discharge does not remove a significant proportion of pesticides applied to fields; considerably more pesticides remain in the soils of a field or are removed through decomposition in the soil than are removed by tail water (surface runoff) or tile drainage.

Before the effects of pesticides in the drainage water can be considered, the drainage system in the San Joaquin Valley should first be described. In the northern and central parts of the valley, the drains empty into the San Joaquin Valley River--both directly and indirectly in the northern part, and only indirectly in the central part. In the southern parts, the effluent from the drain is pumped back into an irrigation canal, and each grower, being responsible for the effluent from his own drains, pumps it into irrigation water going on to his own land. A large-scale San Joaquin Master Drain has been proposed for the western side of the valley. If completed, this Master Drain would remove agricultural drainage water of the west side of the valley and return it to the Sacramento-San Joaquin Delta (see Chapter 1).

Bailey et al. (1967) analyzed pesticides in drains of California and reported that concentrations were lowest in the Sacramento-San Joaquin Delta. Values were higher in the Sacramento Valley and highest in the San Joaquin Valley. The California Department of Water Resources (1968b), monitoring pesticides in the drains of the San Joaquin Valley from 1963 to 1967, found that pesticide concentrations in material in those drains was not significantly higher than concentrations in surface waters in areas of possible disposal (San Francisco Bay area and San Joaquin Valley). On the basis of this and other studies, a subcommittee of the Committee on Government Operations (1967) recommended that surface drainage (tailwater) from irrigated lands, because of its relatively high pesticide content, be excluded from the Master Drain, but stated that these waters were of acceptable quality for irrigation and should be so reused without discharge to surface streams. The subcommittee also recommended that the subsurface drainage waters should be monitored, and that those containing excessive quantities of pesticide compounds should receive appropriate treatment before entering the Master Drain.

Tables 4.3, 4.4, 4.5, and 4.6 show pesticide concentrations in surface and subsurface drain effluents in 1969 and 1970 as determined in the San Joaquin Valley drainage monitoring program. The reporting of chlorinated hydrocarbons and organophosphorus compounds as unknown or unidentified does not indicate unreliability in the analyses. They may be unknown either because of the lack of a standard with which the results can be compared or because of unknown decomposition products. These tables show that the concentrations of pesticides are higher in the surface drains than in the subsurface drains. It can also be noted that many of the identified organophosphorus compounds found in the

Table 4.3 Pesticide Concentrations in Subsurface Drain Effluents in San Joaquin Valley - 1970*

Pesticide	Summation of 17 Stations					
	Times Sampled	Times Detected	Reported Concentration (in ppt)[1]			
			Max.	Min.[2]	Avg.[3]	Avg.[4]
CHLORINATED HYDROCARBONS	60					
BHC		6	7	2	2	5
DDD		1	2	-	0	2
DDE/Dieldrin		1	7	-	0	7
DDT		19	240	2	21	35
Dacthal		3	4780	4	302	1608
Dieldrin		4	43	10	5	21
Heptachlor		2	28	14	3	21
Kelthane		3	45	15	6	32
Lindane		6	2850	3	157	486
Simazine/Atrazine		11	390	5	31	67
Toxaphene		14	630	70	136	262
Complex Chlorinated Compounds as DDT		15	1750	5	130	242
Unknowns as DDT		17	140	4	19	33
Summation of Identified Chlorinated Hydrocarbon Pesticides[5]		43	2850	0[6]	129	180
ORGANIC PHOSPHOROUS COMPOUNDS	60					
Parathion, Methyl		8	170	10	29	76
Thimet		1	74	-	0	74
Unknown as Parathion		10	215	13	23	47

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[1] ppt = parts per trillion

[2] Detected minimum concentration

[3] Average value includes 0 value when chlorinated hydrocarbons were not detected

[4] Average value includes only the detected chlorinated hydrocarbons

[5] Does not include Complex Chlorinated Compounds as DDT or Unknowns as DDT

[6] Actual minimum concentration possible

* California Dept. of Water Resources, 1970

Table 4.4 Pesticide Concentrations in Surface Drain Effluents in San Joaquin Valley - 1970*

Pesticide	Times Sampled	Times Detected	Reported Concentrations (in ppt)[1]			
			Max.	Min.	Avg.[3]	Avg.[4]
CHLORINATED HYDROCARBONS	18					
BHC		3	10	6	5	9
DDD		3	20	3	5	9
DDT		9	450	1	62	82
Dacthal		4	4780	13	712	1246
Kelthane		3	75	4	24	48
Toxaphene		10	4200	88	866	1125
Complex Chlorinated Compounds as DDT		6	132000	80	15182	22746
Unknown as DDT		2	320	3	65	162
Summation of Identified Chlorinated Hydrocarbon Pesticides[2]		16	7265	5	1415	1592
ORGANIC PHOSPHOROUS COMPOUNDS	18					
Ethion		1	225	-	17	225
Thimet		1	35	-	3	35
Methyl Parathion		3	190	10	13	72
Parathion		1	190	-	15	190
Unknown as Parathion		4	175	15	15	59

[1] ppt = parts per trillion

[2] Does not include Complex Chlorinated Compounds as DDT or Unknown as DDT

[3] Average value includes 0 values when chlorinated hydrocarbons were not detected

[4] Average value includes only the detected chlorinated hydrocarbons

*California Dept. of Water Resources, 1970

Table 4.5 Pesticide Concentrations in Subsurface Drain Effluents in San Joaquin Valley - 1969*

Pesticide	Summation of 15 Stations					
	Times Sampled	Times Detected	Reported Concentration (in ppt)[1]			
			Max.	Min.[2]	Avg.[3]	Avg.[4]
CHLORINATED HYDROCARBONS	51					
BHC		12	118	3	5	22
DDD		6	21	5	1	10
DDE/Dieldrin		1	-	-	-	10
DDT		19	109	3	9	23
Dieldrin		8	22	4	2	14
Endrin		1	-	-	-	21
Heptachlor		1	-	-	-	11
Kelthane		3	62	19	2	34
Simazine/Atrazine		2	58	35	2	47
Toxaphene		7	1260	94	61	442
Complex Chlorinated Compounds as DDT		7	695	26	33	242
Unknowns as DDT		24	190	3	14	30
Summation of Identified Chlorinated Hydrocarbon Pesticides[5]	51	37	1325	0[6]	82	113
ORGANIC PHOSPHOROUS COMPOUNDS	41					
Guthion Like		2	2	2	0	2
Unknown as Dinzonin		1	-	-	0	5
Unknown as Parathion		19	22	11	44	11

[1] ppt = parts per trillion

[2] Detected minimum concentration

[3] Average value includes 0 value when chlorinated hydrocarbons were not detected

[4] Average value includes only the detected chlorinated hydrocarbons

[5] Does not include Complex Chlorinated Compounds as DDT or Unknown as DDT

[6] Actual minimum concentration possible

*California Dept. of Water Resources, 1969

Table 4.6 Pesticide Concentrations in Surface Drain Effluents in San Joaquin Valley - 1969*

Pesticide	Times Sampled	Times Detected	Reported Concentrations (in ppt)[1]			
			Max.	Min.	Avg.[3]	Avg.[4]
CHLORINATED HYDROCARBONS	19					
BHC		2	6	5	1	6
DDE		1	-	-	0	6
DDD		4	94	15	5	24
DDT		9	8900	35	557	1177
Dacthal		1	-	-	460	8740
Dieldrin		3	27	7	2	15
Kelthane		2	2800	15	98	1408
Telodrin		1	-	-	0	7
Toxaphene		11	31500	216	2780	4803
Concentrated Chlorinated Compounds as DDT		4	3480	92	237	1125
Unknown as DDT		10	5520	8	331	629
Summation of Identified Chlorinated Hydrocarbon Pesticides[2]	19	16	40400	12	3955	4697
ORGANIC PHOSPHORUS COMPOUNDS	14					
Baytex		1	-	-	0	2
Diazonin		1	-	-	0	5
Imidian		1	-	-	0	5
Methyl Trithion		1	-	-	0	5
Parathion		3	500	6	37	173
Unknown as Parathion		8	2160	7	195	341

[1] ppt = parts per trillion

[2] Does not include Complex Chlorinated Compounds as DDT or Unknown as DDT

[3] Average value includes 0 values when chlorinated hydrocarbons were not detected

[4] Average value includes only the detected chlorinated hydrocarbons

* California Dept. of Water Resources, 1969

surface drains are not found in the subsurface drains. The reason may be the greater biodegradability of these compounds, permitting their destruction during passage through the soil before reaching the subsurface drains.

Direct Application

Pesticides are applied to water for the control of aquatic weeds, rough fish, and aquatic insect pests. To minimize undesirable consequences, these activities are generally managed by professionals. Even so direct application of pesticides to water is (along with surface runoff) one of the two major pathways of pesticides into the aquatic environment, according to a report of the U. S. Department of Health, Education and Welfare (1969). That report also cited instances of damage to the aquatic environment from direct application of pesticides to water. A possible cause given for the damage was insufficient study before application.

Table 4.7 shows the pesticides applied in the San Joaquin Valley in 1970 by the California Department of Water Resources and Irrigation District Agencies. Most of these applications are carried out on water or in the areas surrounding water. As can be seen from the table, almost all the chemicals used are herbicides, which are used to control weeds in irrigation and drainage canals, on ditchbanks, in farm ponds, and in irrigation reservoirs. Pesticides used in the river banks and ditch banks have a high potential of getting into surface water supplied by drift, overlap spray, or runoff.

Dissipation is an extremely important factor in the use of herbicides for control of aquatic and bank weeds. Most of the herbicides registered for use in aquatic situations have water-use restrictions which require at least partial dissipation of the herbicide before normal water use is resumed (Timmer _et al_., 1970). The pathways leading to dissipation are almost as varied as the chemicals themselves. According to Timmer _et al_. (1970) volatilization is the most

Table 4.7 Pesticides Applied in San Joaquin Valley by California Dept. of Water Resources and Irrigation District Agencies (1970)

Pesticides	Number of Reports	Amount Applied (lbs)
A. California Department of Water Resources:		
Atrazine	10	3488.00
Bromacil	14	2676.80
Fenac	5	8628.00
2,4-D	3	3542.00
Simazine	7	1376.80
Copper sulfa-penta-hydrate	5	14823.80
Paraquat	11	647.00
Spreaders	2	28.00
Ansar 138	21	24160.19
DSMA	1	4358.25
Copper hydroxide	1	2079.00
Ansar 170	4	67.00
DNBP	1	198.00
Dalapon	4	173.40
Amitrole	4	251.72
B. Irrigation District Agencies:		
Petroleum solvents	113	3310814.49
Paraquat	15	7634.00
Amitrole	48	8705.13
Ammate	12	2321.80
Ansar 138	42	9834.52
Atrazine	17	5210.80
Diuron	14	2946.40
Hyvar	2	155.20
Simazine	14	8828.40
2,4-D	29	1477.24
2,4,5-T	5	2121.97
Spreaders	7	422.92
Bromacil	9	1340.64
Dormant oils	2	218120.00
Silvex	4	76.00
Sodium chlorate	6	7542.76
PCP	15	3115.35
Tordon	2	1116.24
Ansar 170	83	43886.69
Carbon disulfide	1	240.00
Copper sulfa-penta-hydrate	6	3087.81
Sulfur	2	112.70
Dalapon	30	4706.71
Copper sulfate basic	1	1742.40
Sinox	12	1514.40
Xylene	4	148462.48
DSMA	4	426.00
Trysben, TCB	3	509.96
Borax	2	273.75

important factor in the dissipation of aromatic solvents and acrolein. Sorption process predominates in the disappearance from water of herbicides such as diquat, paraquat, and possibly endothal. Biological and chemical degradation accounts for much of the loss of 2,4-D, silvex, dichlobenil, and other herbicides.

Atmospheric Transport

Atmospheric transport to the aquatic environment can be due to drift of pesticide applied aerially, to volatilization and codistillation of the pesticide from the terrestrial environment, and to wind erosion.

Drifts of 8 to 12 miles from place of application were cited by West (1966). Widespread transport of pesticides by air and rain were reported by Cohen and Pinkerton (1966). Large amounts of DDT were found in Texas, 9 miles distant from and 1,600 feet higher than the place of application (Lasher and Applegate, 1966). Pesticides found in the Sierra Nevada at high altitudes (12,000 feet) were supposed to be wind-borne drift of aerosol DDT released from the Central Valley of California (Cory *et al*., 1970). Risebrough *et al*. (1968) regarded the European-African land areas as the source of chlorinated hydrocarbon insecticides found in airborne dust at Barbados. The insecticides (adsorbed on the dust) were carried some 3,727 miles by the transatlantic movement of the northeast trade winds. Those workers claimed that the amounts of pesticides contributed to the tropical Atlantic ocean by the trade winds are comparable to those carried to the ocean by the major river systems emptying into that portion of the ocean. Hindin (1970) studied the fate of DDT and ethion applied aerially to land area with a cover crop. He concluded that, on average, about 35 percent of the DDT and 50 percent of the ethion did not reach crop height. It was assumed that these percentages of the insecticides were lost to the atmosphere. Several other instances of drifts were cited by Middleton (1966).

The amount and distance of drift is influenced by wind velocity and air movement, temperature, humidity, height of release above ground, and size of droplet, with this last factor affected by pressure, nozzle size, and carrier (Higgins, 1967).

Major ways of loss of some pesticides can be volatilization and codistillation. Acree et al. (1963) reported that codistillation of DDT with water should be considered as a route of loss of DDT. Table 4.8 shows Mitchell's (1966) calculation of the loss of various insecticides based on results reported by Bowman et al. (1964). It illustrates the loss by codistillation 20 hours after the insecticides were introduced into a jar of water containing mosquito larvae.

Table 4.8 Loss of Insecticides from Waters

Insecticide	Starting conc. µg/l	% codistillate (after 20 hrs. at 26.5°C)
Aldrin	24.0	93%
Heptachlor	210.0	91
Chlordane	200.0	70
Dieldrin	24.0	55
Heptachlor epoxide	25.0	42
DDT	25.0	42
Lindane	23.0	30

L. E. Mitchell (1966)

Lloyd-Jones (1971) reported that about half of the DDT applied to field crops may enter the atmosphere by evaporation.

Volatilization depends on the pesticide used. Lichtenstein and Schulz (1964) reported that parathion, unlike some chlorinated hydrocarbon insecticides, was not lost through volatilization. Higgins (1967) reported that, of all of the weed killers, 2,4-D, because of volatility, is the one causing the greatest damage. He also mentioned that this is the area in which selection of formulation is important, for the volatility of 2,4-D depends on its formulation.

Volatilization of a pesticide depends on many other factors, such as air velocity, pesticide concentration, pesticide vapor pressure, temperature, relative humidity, soil water content, and bulk density of the surface soil (Igue, 1970). Pesticide lost to the atmosphere by volatilization and codistillation may travel long distances, not necessarily contaminating the adjacent water environment but perhaps causing a problem elsewhere.

The high summer temperatures in the San Joaquin Valley may make atmospheric transport of pesticides an important route of loss. Significant amounts may thus be lost through volatilization and codistillation. Such losses may travel long distances, however, and how much enters the waters of the San Joaquin Valley cannot be determined from our present knowledge.

Drifts during pesticide application may also be an important route of pesticide loss in San Joaquin Valley. Chapter 3 shows that about half of the amount of pesticides was applied aerially--to 2/3 of the total agricultural area. Transport by aerial drift may thus be considerable, though such drift presents more problems to adjacent land (if crops there are sensitive to pesticides) than it does to the water environments. Of course, pesticide drifts may sometimes be transported hundreds of miles.

Industrial Wastes

Nicholson (1970) reported that the source of pesticides in water that was most significant after run-off was industry. The types of industries involved include producers of basic pesticides, pesticide formulators, cooperage firms that reclaim used pesticide drums, operations that apply wool preservatives, textile plants that mothproof woolen yarns and fabrics with dieldrin, and paper-manufacturing industries that use phenyl mercury acetate as a fungicide.

Disposal of pesticide wastes has become a major problem because these wastes (surplus, discharge, and used containers) may contaminate surface and ground waters. Mitchell _et al_. (1970) did an exploratory study of pesticide migration from waste disposal pits in 1967. They found respective concentrations of DDT, toxaphene, and methyl parathion up to 7.40, 129.50, and 99.20 ppm. Concentrations were highest in the vicinity of the pit bottom, and at the water table (about 9 or 10 feet deep).

The movement of pesticides from waste-disposal sites is a potential hazard both to the environment and to human health. Old and rusting containers represent some of the worst hazards. Small quantities of the chemical can drip out of rusty containers, periling the water supply and human health. The problem of disposal of pesticide wastes is further complicated by the lack of data on pesticide persistence beyond 6 inches of soil depth under different conditions of temperature, pressure, oxygen tension, and other environment conditions. The California Department of Agriculture requires that all pesticide containers be discarded at Class I dump sites (capable of handling hazardous material by being so situated that no liquid drainage can later reach ground waters). There are presently only eleven Class I dump sites in the state, none of them in the San Joaquin Valley (San Francisco _Sunday Examiner and Chronicle_, February 28, 1971). Used pesticide containers, mostly 1-gallon or 5-gallon cans, have piled up in many locations, largely because of the difficulty of finding an approved location for dumping them. Dump sites approved for disposal of agricultural chemicals are few and far between. A special disposal campaign, conducted jointly in March 1971 by the Department of Agriculture and Public Health and the Water Resources Control Board, attempted to alleviate the problem temporarily by identifying existing dump sites that might be temporarily approved for use in the campaign. (More about this campaign in Chapter 8.)

Municipal Wastes

Pesticides may also enter water along with municipal wastes such as sewage effluents. A review (1971) of pesticide monitoring programs in California prepared by an Ad Hoc Working Group of the Pesticide Advisory Committee to the State Department of Agriculture reported that substantial quantities of pesticides, mainly chlorinated hydrocarbons, have been discharged to surface waters through municipal and industrial waste discharges. The quantities of waste water discharged are so large that even low concentrations of pesticides in the water result in a large emission. The group pointed out that the discharge of the Los Angeles County Sanitation Districts contained high concentrations of pesticides at least from December 1969 through May 1970. Los Angeles County Sanitation District emissions of total identified chlorinated hydrocarbons during that period exceeded all of the other known discharges of pesticides to the ocean by a wide margin. The group also pointed out that if such emissions from the Los Angeles County Sanitation Districts outfalls have been occurring for a number of years, this one source may overshadow all other sources of DDT in Southern California marine waters.

Recently Burnett (1971) studied the distribution of DDT residues in *Emerita analoga* Stimpson along Coastal California and concluded that animals near the Los Angeles County sewer outfall contain over 45 times as much DDT as animals near major agricultural drainage areas. The probable source of this high concentration of DDT in the sewer outfall was thought to be a plant that manufactures DDT. Burnett pointed out that the above observation suggested that historically the buildup of residues in California coastal marine organisms could be attributed, to a significant degree, to industrial waste discharge rather than merely to extensive agricultural usage.

Not enough information is available on the pesticides concentration in municipal wastes in the San Joaquin Valley area.

Agricultural Wastes

Pesticides may enter water with wastes such as plant residues from agriculture and from the food industry.

Hindin (1970) reported that the major mode of DDT disappearance from a treated plot is by crop removal. By harvest time, some of the less stable organic phosphorus compounds may be metabolized by the plant to nontoxic end products. Plants can metabolize DDT also, though much more slowly, so it may persist with crop residue for a long time.

Wastes or residues from grasslands, grainfields, rangelands, and orchards are sometimes burned to rid the land of the material or to control a disease. Such burning may emit some pesticides that do not degrade in the burning operation. Such pesticides entering the air may find their way into water. Plant residues are sometimes left on the soil or incorporated into the soil and as the plant material decomposes it returns metabolic products back to the soil.

Hart (1966) reported that plant residues are not generally a serious pollutant of water.

Accidents and Spills

Some other sources of entry of pesticides include accidents and spills. Several instances of accidents and spills are reported elsewhere (Nicholson, 1970; U. S. Department of HEW, 1969; West, 1966). Accidents and spills occur during storage, packaging, transport, and application. Although of serious concern, they affect only a localized area for a short period. In addition, with careful measures taken, most spills can be cleaned up. Therefore pesticide contamination by spills and accident is not a major route of pesticides to the water environment of the San Joaquin Valley.

Seasonal Variation of Pesticide Use in the San Joaquin Valley and Pesticide Concentrations in the San Joaquin River and Surface Drains

The time that a pesticide may take to reach the river from its initial point of application will vary with the route it takes. This is generally in the following order:

Atmospheric transport and Direct application to water < Surface runoff and Surface drainage < Subsurface drainage

Figures 4.3, 4.4, and 4.5 show the amounts of chlorinated hydrocarbon pesticides applied to lands of the San Joaquin Valley, the total concentrations of chlorinated hydrocarbon compounds in surface drains of the valley, and the total concentration of pesticides, mostly chlorinated hydrocarbons, in the San Joaquin River at different seasons. The amounts of chlorinated hydrocarbon pesticides applied were highest in summer months, and the concentrations of chlorinated hydrocarbons in the drains were also highest in the same months. The concentrations of pesticides in the San Joaquin River, since they were obtained in 1964 and 1965, cannot really be correlated with the drainage and use data, even though the concentrations of pesticides in the river were also highest in the same summer months. Bailey *et al*. (1967) proposed that these maximum concentrations in the river were due to reduced natural river flows coupled with increased irrigation drainage flows from the tile drains.

References, Chapter 4

Acree, F., Jr., M. Beroza and M.C. Bowman. 1963. Codistillation of DDT with water. J. Agr. Food Chem. 11: 278-80.

Aksenov, V.B. and I.V. Poluboiavinova. 1970. Hygenic study of the soil in connection with the use of 2,4-D herbicide. Gig. Sanit. 35:103-23.

Ashton, F.M. 1961. Movement of herbicides in soil with simulated furrow irrigation. Weeds 9:612-19.

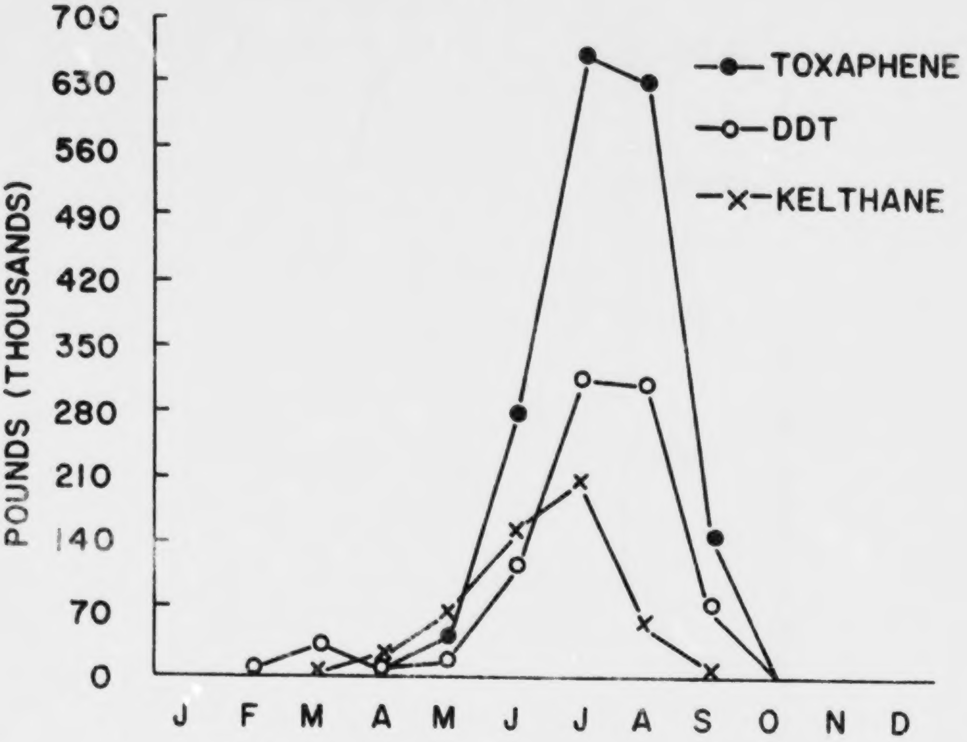

Figure 4.3 Seasonal variation of pesticides used in San Joaquin Valley

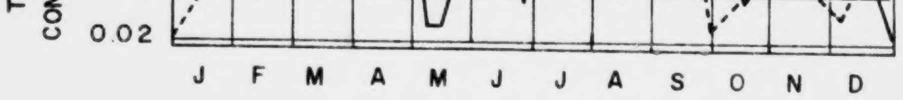

Figure 4.4 Seasonal variation of the concentrations of total pesticides identified in San Joaquin River (Bailey et al., 1967)

- - - 1965

—— 1964

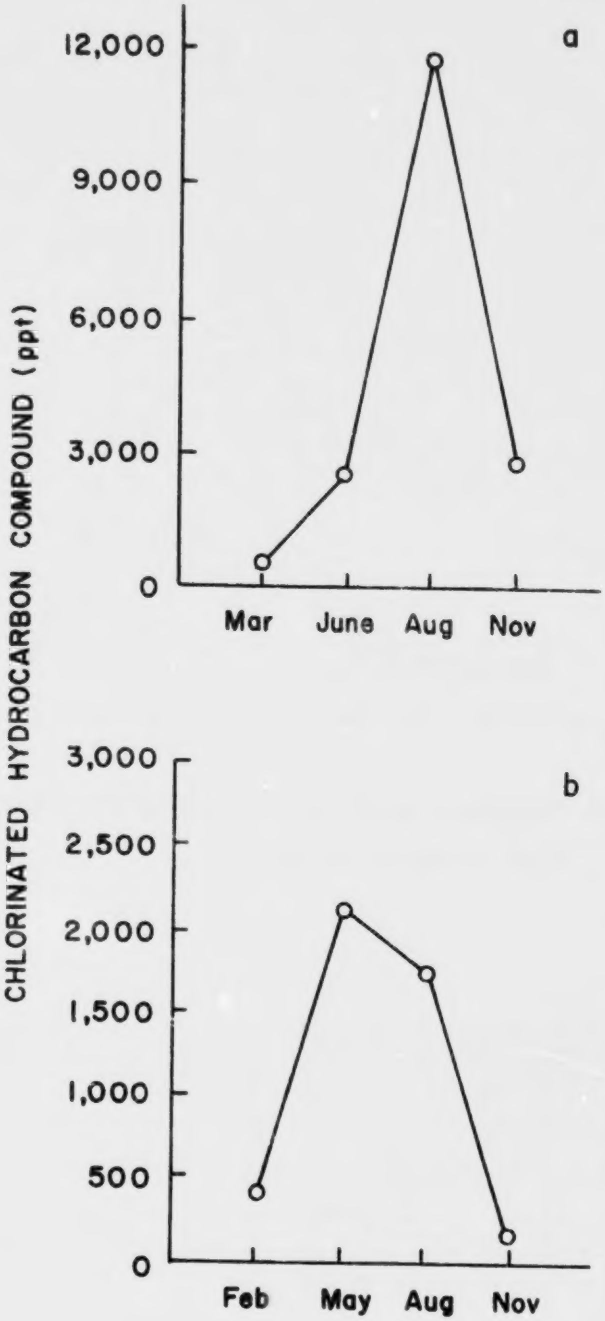

Figure 4.5 Seasonal variation of average concentrations of chlorinated hydrocarbon pesticides found in surface drainage systems in San Joaquin Valley. (a) 1969 (b) 1970 (California Department of Water Resources. 1969, 1970)

Bailey, G.W. 1966. Entry of biocides into water courses. In: Agricultural Waste Waters. Los Angeles, University of California, Water Resources Center. p. 94-103 (Water Resources Center Report No. 10).

Bailey, G. W. and J. L. White. 1970. Factors influencing the adsorption, desorption, and movement of pesticides in soil. Res. Rev. 32:29-93.

Bailey, T. E. and J. R. Hannum. 1967. Distribution of pesticides in California. J. Sanit. Eng. Div., Amer. Soc. Civil Eng., 93:27-43.

Ballard, T. M. 1971. Role of humic carrier substances in DDT movement through forest soils. Soil. Sci. Soc. Amer. Proc. 35:145-47.

Beran, F. and J. A. Guth. 1965. Organic insecticides in various soils, with particular reference to possible ground water pollution. Pflanzenschutzberichte, 33:65-117.

Bowman, M.C., F. Acree, Jr., C.S. Lofgren, and M. Beroza. 1964. Chlorinated insecticides: fate in aqueous suspension containing mosquito larvae. Science 146:1480-81.

Bunnett, R. 1971. DDT residues: distribution of concentrations in Emerita analoga (Stimpson) along coastal California. Science 174:606-8.

California Dept. of Water Resources. 1968a. The fate of pesticides applied to irrigated agricultural land. Sacramento, California (Its Bulletin No. 174-1).

California Dept. of Water Resources. 1968b. Progress report. San Joaquin Drainage investigation quality and treatment studies through Dec. 31, 1967. Sacramento, California (Its Bulletin No. 174-2).

California Dept. of Water Resources. 1969. San Joaquin Valley drainage monitoring program, 1969 summary, Sacramento, California.

California Dept. of Water Resources. 1970. San Joaquin Valley drainage monitoring program, 1970 summary, Sacramento, California.

California Water Resources Control Board. 1971. A Review of Pesticide Monitoring Programs in California. Prepared by Ad Hoc Working group of the Pesticide Advisory Committee to the State Department of Agriculture, Sacramento, California.

Cohen, J. M. and C. Pinkerton. 1966. Widespread translocation of pesticides by air transport and rain-out. In: Organic Pesticides in the Environment. Washington, Amer. Chem. Soc., p. 163-76. (Adv. Chem. Ser. 60).

Corey, L., P. Fjeld and W. Serat. 1970. Distribution patterns of DDT residues in the Sierra Nevada Mountains. Pest. Monit. J. 3:204-11.

Edwards, C.A., A.R. Thompson, K.I. Beymon and M.J. Edwards. 1970. Movement of dieldrin through soils. I. From arable soils into ponds. Pestic. Sci. 1:169-73.

Foy, C.L. and S.W. Bingham. 1969. Some research approaches toward minimizing herbicidal residues in the environment. Residue Rev. 29:105-35.

Grasso, C., G. Bernardi and E. Mariottini. 1968. Detection of pesticides in underground waters. Ann. Sanit. Publ. 29:1029-32.

Gray, R.A. and A.J. Weierich. 1968. Leaching of five thiocarbamate herbicides in soils. Weed Sci. 16:77-79.

Gunther, F. A., W. E. Westlake, and P. S. Jaglan. 1968 . Reported solubilities of 738 pesticide chemicals in water. Residue Rev. 20:1-148.

Harris, C. I. 1966. Adsorption, movement and phytotoxicity of monuron and s-triazine herbicides in soils. Weeds 14, 6-10.

Harris, C. I. 1967. Movement of herbicides in soil. Weeds 15, 214-16.

Harris, C. I. 1969. Movement of pesticides in soil. J. Agr. Food. Chem. 17, 80-82.

Hart, S. A. 1966. Agricultural wastes and the waste water problem. In: Agricultural Waste Waters. Water Resources Center, University of California, 14-16.

Helling, C. S. and B. C. Turner. 1968. Pesticide mobility: Determination by soil thin-layer chromatography. Science 162, 562-63.

Higgins, R. E. 1967. Hazards of drift phytotoxicity and hazards to animals. Proc. Western Weed Control Conf. 21, 28-30.

Hindin, E. 1970. Occurrence of pesticides in aquatic environments: Part 1. Insecticide distribution on an agricultural plot. Pullman, Washington, Washington State University, Technical Extension Service. (College of Engineering).

Igue, K. 1970. Volatility of organochlorine insecticides from soil. A Ph.D. dissertation. University of California, Riverside.

Johnson, H. P. and W. C. Moldenhauer. 1970. Pollution by sediment: Sources and the detachment and transport processes. In: Agricultural Practices and Water Quality. Ames, Iowa, Iowa State University, p. 3-20.

Johnston, W. R., F. T. Ittihadich, K. R. Craig and A. F. Pillsburg. 1967. Insecticides in tile drainage effluent. Water Resour. Res. 3:525-37.

Laheer, C. and H. G. Applegate. 1966. Pesticides at Presidio III. Soil and water. Texas J. Sci. 18:386-95.

Leh, H. O. 1968. Studies on the vertical movement of herbicides in the soil with special regard to the possibilities of ground water contamination. Nachr. Bl. dt. Pfl Schutzdienst. Stuttg. 20:99-106.

Lichtenstein, E. P. 1958. Movement of insecticides in soils under leaching conditions. J. Econ. Entomol. 51:380-83.

Lichtenstein, E. P. 1970. Fate and movement of insecticides in and from soils. In: Pesticides in the Soil; International symposium. East Lansing, Michigan, Michigan State University, p. 101-6.

Lichtenstein, E. P. and K. R. Schulz. 1964. The effect of moisture and microorganisms on the persistence and metabolism of some organophosphorus insecticides in soils, with special emphasis on parathion. J. Econ. Entomol. 57:618-27.

Lloyd-Jones, C. P. 1971. Evaporation of DDT. Nature 229:65-6.

McCarty, P. L. and P. H. King. 1966. The movement of pesticides in soils. Eng. Bull., Purude University, Ext. Ser. No. 121:156-71.

Middleton, J. T. 1965. The presence, persistence and removal of pesticides in air. In: Research in Pesticides, edited by C. O. Chichester. New York Academic Press, p. 191-8.

Mitchell, L. E. 1966. Pesticides: properties and prognosis. In: Organic Pesticides in the Environment. Washington, Amer. Chem. Soc., p. 1-22. Adv. Chem. Ser. 60.

Mitchell, W. G., D. A. Parsons, P. F. Sand, D. D. Lynch, and W. S. Cook, Jr. 1970. An explanatory study of pesticide migration from waste disposal pits, 1967. Washington, U. S. Dept. of Agriculture, Agricultural Research Service. p. 14.

Niagara Chemical Division. 1971. Insecticide-Miticide. Middleport, N. Y.

Nicholson, H. P. 1970. The pesticide burden in water and its significance, In: Agricultural Practices and Water Quality. Ames, Iowa, Iowa State, p. 183-93.

Nicholson, H. P. and D. W. Hill. 1970. Pesticide contaminants in water and mud and their environmental impact. In: Relationship of Agriculture to Soil and Water Pollution; Cornell University Conference on Agricultural Waste Management. Ithaca, New York, Cornell University, p. 171-79.

Risebrough, R. W., R. J. Huggett, J. J. Griffin and E. D. Goldberg. 1968. Pesticides-Transatlantic movement in the Northeast Trades. Science 159:1233.

Storie, R. E. and W. W. Wein. 1951. Generalized Soil Map of California. Berkeley, California., Calif. Agr. Exp. Sta. Ext. Ser. (Manual 6).

Swift, J. E. 1966. Pesticides, wildlife and water relationship in California, In: Agricultural Waste Waters. Los Angeles, Water Resources Center, University of California. p. 9-14.

Swoboda, A. R. and G. W. Thomas. 1968. Movement of parathion in soil columns. J. Agr. Food Chem. 16:923-27.

Timmer, F. L., P. A. Frank and R. J. Demint. Herbicide residues in agricultural water from control of aquatic and bank weeds. In: Agricultural Practices and Water Quality. Ames, Iowa, Iowa State University. p. 193-208.

U. S. Dept. of Agriculture. Soil Conservation Service. 1970. Comprehensive Framework Study, California Region. Appendix VIII. Watershed Management. Prepared by the California Region Framework Study Committee for the Pacific Southeast Inter-Agency Committee Water Resources Council.

U.S. Dept. of Health, Education, and Welfare. 1969. Report of the Secretary's Commission on pesticides and their relationship to environmental health. Part I and II. Washington, Govt. Print. Off.

U.S. House Committee on Government Operations. 1967. Water Pollution - Central and Northern California. Hearings before a subcommittee of the Committee on Government Operations, House of Representatives, Nineteenth Congress, first session. Washington, Govt. Print. Off.

U.S. Rubber Company Chemical Division. Agricultural Chemicals.

West, I. 1966. Biological effects of pesticides in the environment. In: Organic Pesticides in the Environment. Washington, Amer. Chem. Soc. p.38-53. (Adv. Chem. Ser. 60).

Westlake, W.E. and F.A. Gunther. Occurence and mode of introduction of pesticides in the environment. In: Organic Pesticides in the Environment. Washington, Amer. Chem. Soc. p.110-21. (Adv. Chem. Ser. 60).

CHAPTER 5

DEGRADATION, METABOLISM, AND PERSISTENCE OF PESTICIDES IN THE AQUATIC ENVIRONMENT

Degradation of Pesticides

When a pesticide is applied to soil or water it does not always remain in the same form for long. It may be transformed into other chemicals--biologically by soil and water microorganisms, nonbiologically by photolysis, or by chemical means. These transformations often affect the persistence, toxicity, and other physicochemical properties of the pesticide. Study of the effect of pesticides on the aquatic environment therefore requires knowledge of the degradation products and their toxicities and persistences.

The metabolic and degradation products of pesticides in soils, water, plants, and animals were recently discussed in great detail by a number of investigators (Menzie, 1969; Kearney and Kaufman, 1969; Ware and Roan, 1971; White-Stevens, 1971; Dahm, 1970; Kearney, 1966). Since this study is concerned primarily with the effects of pesticides on the aquatic environment, only the degradation products in soil and water are considered. These products of pesticides selected from the top 100 pesticides used in the San Joaquin Valley, are shown in Table 5.1. The column "Agents" indicates whether the degradation product is microbial or photochemical and whether it was degraded in soil or water. As can be seen, information available on the degradation of pesticides in water is scant compared with that in soil. However, the degradation products found in soil could also be detected in water. The main differences between the soil and water environments are in the concentrations of pesticide, adsorbate, or microorganisms.

Some of the ways in which pesticides are degraded biologically are by hydrolysis, hydroxylation, dehalogenation, dehydrohalogenation, desulfuration (= oxidation), O-dealkylation, N-dealkylation, reduction, conjugation, and ring

Table 5.1 Degradative and Metabolic Products of Pesticides

Pesticide	Degradation Products	Degradation Agent	Reference
Organochlorine insecticides:			
DDT	DDD	Soil microorganisms, anaerobic conditions	Guenzi and Beard (1967)
		Soil microorganisms	Chacko and Lockwood (1966)
		Soil microorganisms	Matsumura and Boush (1968)
		Water microorganism	Wedemeyer (1966)
		Water microorganism	Miskus et al. (1965)
		Water microorganisms	Matsumura et al. (1971)
		Great number of bacteria	Johnson et al. (1967)
		Yeast	Kallman and Andrews (1963)
		UV light	Moier at al. (1969)
		UV radiation - soil	Baker and Applegate (1970)
	DDE	Soil microorganisms, anaerobic conditions	Guenzi and Beard (1967)
		Soil microorganisms	Lichtenstein et al. (1971)
		Water - diatom	Keil and Priester (1969)
		Water microorganism	Matsumura et al. (1971)
		Clay surface	Lopez (1970)
		UV light	Moier et al. (1969)
		UV radiation - soil	Baker and Applegate (1970)
	Dicofol	Soil microorganisms, anaerobic conditions	Guenzi and Beard (1967)
		Soil microorganisms	Matsumura and Boush (1968)
		Soil microorganisms	Lichtenstein et al. (1971)
	DDA	Soil microorganisms, anaerobic conditions	Guenzi and Beard (1967)
	DBP (4,4-dichlorobenzophenone)	Soil microorganisms, anaerobic conditions	Guenzi and Beard (1967)
		UV light	Moier et al. (1969)
		UV radiation - soil	Baker and Applagate (1970)
	p-Chlorobenzoic acid	Soil microorganisms, anaerobic conditions	Guenzi and Beard (1967)
	DDMU	UV radiation - soil	Baker and Applegate (1970)
	DDMS (1-bis(p-chlorphenyl)-ethane)	Water microorganisms	Matsumura et al. (1971)
Endosulfan	Endosulfan diol	Alkaline hydrolyses	Crosby (1970)
Kelthane	4,4-Dichlorobenzophenone	Alkaline hydrolyses	Crosby (1970)
	Chloroform	Alkaline hydrolyses	Crosby (1970)
Methoxychlor	Dimethoxybenzophenone	Photolyses	Fernandes (1966)
	p-Methoxyphenol	Photolyses	Fernandes (1966)
	Anisic acid	Photolyses	Fernandez (1966)
Toxaphene	Poorly understood		Menzie (1969), Dahm (1970), Fukuto and Sims (1971)
Organophosphate insecticides:			
Baytex	Fenthion sulfoxide	UV light	Mitchell et al. (1968)
		Sunlight	Metcalf et al. (L963)
	Fenthion sulfone	Sunlift	Metcalf et al. (1963)

Table 5.1 - Continued

Pesticide	Degradation Products	Degradation Agent	Reference
	4-Methylthio-m-cresol (suspected product)	Natural river water	Eichelberger and Lichtenberg (1971)
	Dimethyl-o-thiophosphoric acid (suspected product)	Natural river water	Eichelberger and Lichtenberg (1971)
Carbophenothion	Carbophenothion sulfoxide	UV light	Mitchell *et al.* (1968)
Dimethoate	Desmethyl dimethoate	Alkali hydrolysis, pH = 11	Brady and Aurther (1963)
	O,O-Dimethyl phosphorodithioic acid	Alkali hydrolysis, PH = 11	Brady and Aurther (1963)
	Carboxy derivative	Alkali hydrolysis, pH = 11	Brady and Aurther (1963)
	O,O-Dimthyl phosphorodithioic acid	Alkali hydrolysis, pH = 11	Brady and Aurther (1963)
Diazinon	2-Isopropyl-4-methyl-6-hydroxypyrimidine	Hydrolyses in soil	Konrad *et al.* (1967)
		Soil microorganisms	Sethunathan and Yoshida (1969)
	Diethyl thiophosphoric acid	Hydrolyses in soil	Konrad *et al.* (1967)
Diphenamid	N-methyl-2,2-diphenylacetamide	Soil microorganisms	Golab *et al.* (1969)
		UV light	Rosen (1967)
	N-Formyl-2,2-diphenylacetamide	UV light	Rosen (1967)
	2,2-Diphenylacetamide	Soil microorganisms	Golab *et al.* (1968)
	2,2-Diphenylacetic acids	Soil microorganisms	Golab *et al.* (1968)
	Benzhydrol	UV light	Rosen (1967)
	Benzophenone	UV light	Rosen (1967)
	Benzoic acid	UV light	Rosen (1967)
Dylox	Dimethyl 2,2-dichlorovinyl phosphate	Alkaline conditions	Mattson *et al.* (1955)
	Dimethyl phosphate	Acid conditions	Menzie (1969)
	Trichloroethanol	Acid conditions	Menzie (1969)
	Desmethyl trichlorfon	Acid Conditions	Menzie (1969)
	O-Methyl-2,2,2-trichloro-1-hydroxyethyl phosphonic acid	Microorganisms	Zayed *et al.* (1965 a, b)
	2,2,2-Trichloro-1-hydroxyethyl phosphonic acid	Microorganisms	Zayed *et al.* (1965 a, b)
Disyston	Disulfoton sulfone	UV light	Mitchell *et al.* (1968)
	Disulfoton sulfoxide	UV light	Mitchell *et al.* (1968)
Malathion	Diethyl malate	Soil microorganisms	Matsumura and Boush (1966)
	Desmethyl malathion	Soil microorganisms	Matsumura and Boush (1966)
	Thiomalic acid	Chemical hydrolyses	Konrad *et al.* (1969)
		Soil	Konrad *et al.* (1969)
	Dimethyl thiophosphoric acid	Chemical hydrolyses	Konrad *et al.* (1969)
		Soil	Konrad *et al.* (1969)
		Hydrolysis in acid pH	Muhlmann and Schroder (1957)
	Diethyl thiomalate	Chemical hydrolysis	Konrad *et al.* (1969)
		Soil	Konrad *et al.* (1969)

Table 5.1 - Continued

Pesticide	Degradation Products	Degradation Agent	Reference
	Diethyl fumarate	Hydrolyses in basic pH	Muhlmann and Schroder (1957)
	Dimethyl phosphorodithioic acid	Hydrolyses in basic pH	Muhlmann and Schroder (1957)
	2-Mercaptodiethyl succinate	Hydrolyses in acid pH	Muhlmann and Schroder (1957)
Methyl parathion		Metabolism nearly similar to parathion. Unlike parathion, on photolyses methyl parathion gives rise only to the corresponding paraoxon, which in turn gives rise to a less polar compound.	Dahm (1970)
Parathion	Aminoparathion		Menzie (1969)
		Soil microorganisms	Lichtenstein and Schulz (1964)
		Soil microorganisms	Miller *et al*. (1966)
		Lake sediments - microorganisms	Graetz *et al*. (1970)
		Rhizobium	Mick and Dahm (1970)
	p-Nitrophenol	Soil microorganisms	Lichtenstein and Schulz (1964)
		Lake sediments (sterilised)	Graetz *et al*. (1970)
		Direct sunlight and irradiation by Hg discharge lamp	Sandi (1958)
		Sunlight	Menzie (1969)
		Water	Eichelberger and Lichtenstein (1971)
	p-Aminophenol	Soil microorganisms	Lichtenstein and Schulz (1964)
	Diethyl thiophosphoric acid	Lake sediments (sterilised)	Graetz *et al*. (1970)
	Diethyl-ortho-thiophosphoric acid	Water	Eichelberger and Lichtenstein (1971)
	DEPTA (O,O-Diethyl phosphorothioic acid)	Rhizobium	Mick and Dahm (1970)
	Paraoxon	UV light	Koivistoinen (1962)
	S-Ethyl parathion	UV light	Koivistoinen (1962)
	S-Phenyl parathion	UV light	Koivistoinen (1962)
Phorate	Phosphorodithioate sulfoxide	Soil microorganisms	Ahmed *et al*. (1958)
		UV light	Mitchell *et al*. (1968)
	Phosphorothiolate sulfide	Soil microorganisms	Ahmed *et al*. (1958)
	Phosphorothiolate sulfone	Soil microorganisms	Ahmed *et al*. (1958)
		UV light	Mitchell *et al*. (1968)
Phosalone	Phosalone - oxon	Soil	Colinese and Terry (1968)
	Diethyl phosphorodithioic acid	Soil	Colinese and Terry (1968)
	Diethyl phosphorothioic acid	Soil	Colinese and Terry (1968)
	A substituted phenoxazone	Soil	Colinese and Terry (1968)
Other insecticides:			
Carbaryl	1-Naphthyl N-hydroxymethylcarbamate	Soil fungus	Liu and Bollag (1971)
	4-Hydroxy-1-naphthyl methylcarbamate	Soil fungus	Lui and Bollag (1971)
	5-Hydroxy-1-naphthyl methylcarbamate	Soil fungus	Lui and Bollag (1971)

Table 5.1 - Continued

Pesticide	Degradation Products	Degradation Agent	Reference
	1-Naphthol	Soil water	Lichtenstein *et al*. (1966)
		UV light	Crosby and Leitis (1964)
	Phthalic acid	UV light	Crosby and Leitis (1964)
Herbicides:			
Atrazine	Hydroxyatrazine	Catalysed by adsorption on clays	Russell *et al*. (1968)
		Catalysed by adsorption in soil	Armstrong *et al*. (1967)
		Soil fungi	Couch *et al*. (1965)
		Soil	Obien *at al* (1969)
	2-Chloro-4-amino-6-isopropylamino-s-triazine	Chemical hydrolyses in soil	Skipper *et al*. (1967)
		Soil fungi	Kaufman and Blake (1970)
	2-Chloro-4-ethylamino-6-amino-s-triazine	Soil fungi	Kaufman and Blake (1970)
Amitrole	3-Amino-1,2,4,-triazolyl alanine	*E. coli*	Williams *et al*. (1965)
	Urea	UV light	Plimmer *et al*.(1967)
	Cyanamide	UV light	Plimmer *et al*.(1967)
2,4-D	2,4-Dichlorophenol	Soil microorganisms	Steenson and Walker (1956)
		Soil microorganisms	Loos *et al*. (1967)
		Bacteria	Bollag *et al*. (1968a)
		Soil microorganisms	Kearney *at al*. (1968)
		UV light	Crosby and Tutass (1966)
	4-Chlorocatechol	Soil microorganisms	Steenson and Walker (1956)
		Soil microorganisms	Kearney *et al*. (1968)
		UV light	Crosby and Tutass (1966)
	3,5-Dichlorocatichol	Soil microorganisms	Kearney *et al*. (1968)
		Microorganisms	Faulkner and Woodcock (1964)
		Bacteria	Bollag *et al*. (1968b)
		Soil microorganisms	Evans (1961)
	5-OH-2,4-D	Soil microorganisms	Kearney *et al*. (1968)
		Microorganisms	Faulkner and Woodcock (1964)
	6-OH-2,4-D	Soil microorganisms	Evans (1961)
	4-OH-2,5-D	Microorganisms	Faulkner and Woodcock (1964)
	α-Chloromutonic acid	Soil microorganisms	Fernley and Evans (1959)
		Soil microorganisms	Evans (1961)
	β-Chloromutonic acid	Soil microorganisms	Evans (1961)
	α-Chloro-γ-carboxymethylene-Δ^{α}Butenolide	Bacteria	Bollag *et al*. (1968b)
	2-Chloro-4-hydroxy phenoxy acetic acid	UV light	Crosby and Tutass (1966)
	4-Chloro-2-hydroxy phenoxy acetic acid	UV light	Crosby and Tutass (1966)
	1,2,4-Benzenetriol	UV light	Crosby and Tutass (1966)

Table 5.1 - Continued

Pesticide	Degradation Products	Degradation Agent	Reference
Dalapon	Pyruvic acid	Soil microorganism	Kearney et al. (1964a)
		Cell free enzime from bacteria	Kearney et al. (1964b)
	Monochloropropionate	Many microorganisms	Menzie (1969)
	α-Chloroacrylate	Cell free enzime from bacteria	Kearney et al. (1964b)
	α-Chloro-α-hydroxypropionate	Cell free enzime from bacteria	Kearney et al. (1964b)
Dacthal	Monomethyl derivative	Soil	Skinner et al. (1964)
	Free dicarboxyl analog	Soil	Skinner et al. (1964)
	2,3,5,6-Tetrachloroterephthalic acid (a predicted product)	Irradiation, >290mμ	Crosby and Li (1969)
Diuron	3-(3,4-Dichlorophenyl)-1-methylurea	Soil	Dalton et al. (1966)
	1-(3,4-Dichlorophenyl) urea	Soil	Daltou et al. (1966)
	3,4-Dichloroaniline	Soil	Dalton et al. (1966)
MCPA	4-Chloro-2-methylphenol	Soil microorganism	Bollag et al. (1967)
	6-OH-MCPA	Soil bacteria	Gaunt and Evans (1961)
	5-Chloro-3-methylcatechol	Soil bacteria	Gaunt and Evans (1961)
	α-methyl-α-chloromuconic acid	Soil bacteria	Gaunt and Evans (1961)
	γ-Methyl-γ-carboxymethylene-Δα-butenolide	Soil bacteria	Gaunt and Evans (1961)
	α-Methylmaleylacetic acid	Soil bacteria	Gaunt and Evans (1961)
	2-Methyl-4-chlorophenol	Bacteria	Steenson and Walker (1957)
	4-Chloro-2-methyl-5-hydroxyphenoxy acetic acid	Soil fungi	Faulkner et al. (1965)
Paraquat	1-Methyl-4-carboxypyridinium	Soil bacteria	Bozarth et al. (1966)
		UV light	Funderburk et al. (1966)
		UV light	Slade (1965)
	1-Methyl-4,4'-dipyridinium ion	Bacterial isolate	Funderburk and Bozarth (1967)
	Methyl amine hydrochloride	UV light	Slade (1965)
Propanil	Propionic acid	Soil microorganism	Bartha et al. (1969)
	3,4-Dichloroaniline	Soil microorganism	Bartha et al. (1969)
	1,3-Bis(3,4-dichlorophenyl) triazine	Soil	Plimmer et al. (1970)
	3,3',4,4'-Tetrachloroazobenzene	Soil microorganisms	Bartha et al. (1969)
		Soil microorganisms	Chisaka and Kearney (1970)
	3,3',4'-Trichloro-4-(3,4-dichloroanilino) azobenzene	Soil	Linke (1970)
Pyrazon	5-Amino-4-chloro-3(2H)-pyridazinone	Soil bacteria	Engebild and Jensen (1969)
		Soil microorganism	Smith and Meggitt (1970)
Sinox	3-Amino-5-nitro-o-cresol	Soil bacteria	Tewfik and Evans (1966)
	3-Methyl-5-nitrocatechol	Soil bacteria	Tewfik and Evans (1966)

Table 5.1 - Continued

Pesticide	Degradation Product	Degradation Agent	Reference
	3-Methyl-5-aminocatechol	Soil bacteria	Tewfik and Evans (1966)
	2,3,5-Trihydroxytoluene	Soil bacteria	Tewfik and Evans (1966)
Simazine	3-Amino-5-nitro-o-cresol	Soil bacteria	Hamdi and Mohamed (1970)
	Hydroxysimazine	Soil microorganisms	Harris (1965)
	2-Chloro-4-amino-6-ethylamino-s-triazine	Soil microorganisms	Kearney *et al*. (1965)
TCA	Chloroform	UV light	Banerji and Dher (1924)
	Carbon dioxide	UV light	Banerji and Dher (1924)
Trifluralin	α,α,α-Trifluoro-2,6-dinitro-N-propyl-p-toluidine	Aerobic degradation in soils	Probst *et al*. (1967)
		Anaerobic degradation in soils	Probst *et al*. (1967)
		UV light	Probst and Tepe (1969)
	α,α,α-Trifluoro-2,6-dinitro-p-toluidine	Aerobic degradation in soils	Probst *et al*. (1967)
		UV light	Probst and Tepe (1969)
	α,α,α-Trifluoro-5-nitro-N-propyl-toluene-3,4-diamine	Aerobic degradation in soils	Probst *et al*. (1967)
		Anaerobic degradation in soils	Probst *et al*. (1967)
	α,α,α-Trifluoro-5-nitro-toluene-3,4-diamine	Aerobic degradation in soils	Probst *et al*. (1967)
	α,α,α-Trifluoro-6-nitro-2-nitroso-p-toluidine	UV light	Probst and Tepe (1969)
	α,α,α-Trifluorotoluene-3,4,5-triamine	Aerobic degradation in soils	Probst *et al*. (1967)
		Anaerobic degradation in soils	Probst *et al*. (1967)
	α,α,α-Trifluoro-N,N-dipropyl-toluidine-3,4,5-triamine	Anaerobic degradation in soils	Probst *et al*. (1967)
	α,α,α-Trifluoro-N-propyl-toluene-3,4,5-triamine	Anaerobic degradation in soils	Probst *et al*. (1967)
Other pesticides:			
Chlorobenzilate	4,4'-Dichlorobenzophenone	Yeast	Miyazaki *et al*. (1970)
	4,4'-Dichlorobenzilic acid	Yeast	Miyazaki *et al*. (1970)
	Chlorobenzilate	Yeast	Miyazaki *et al*. (1970)
DBCP	n-Propanol	Soil	Thomason *et al*. (1971)
Maneb	Similar to Nabam		Fukuto and Sims (1970)
Nabam	CS_2	Soil	Munnecke *et al*. (1962)
		Chemical degradation	Ludwig and Thorn (1960)
	H_2S	Soil	Munnecke *et al*. (1962)
		Chemical degradation	Ludwig and Thorn (1960)
	Carbonyl sulfide	Soil	Moje *et al*. (1964)
	Ethylenediamine	Chemical degradation	Ludwig and Thorn (1960)
	Ethylene thiourea	Chemical degradation	Ludwig and Thorn (1960)
	Ethylene thiuramdisulfide	Chemical degradation	Ludwig and Thorn (1960)
	Ethylene thiurammonosulfide	Chemical degradation	Ludwig and Thorn (1960)
Telone	3-Chloroallyl alcohols	Chemical hydrolyses in soils	Thomason *et al*. (1971)
	3-Chloroacrylic acid	Chemical hydrolyses and then by soil bacteria	Thomason *et al*. (1971)
		Chemical hydrolyses and then by soil bacteria	Belsen and Castro (1971)

cleavage (Kaufman, 1970; Dahm, 1970; Menzie, 1969; Kearney and Helling, 1969).

Nonbiological degradation may be mineral- and organic-matter surfaces in the soil, by water, and by photolysis. Nonbiological degradation is discussed in detail elsewhere (Crosby and Li, 1969; Crosby, 1970). The dividing line between biological and nonbiological reactions is not always clear. Difficulties in obtaining sterile soil without changing the physicochemical properties of soil have precluded clear distinctions between the two processes. Furtner, degradation pathways and products are often the same in the different processes, so that it is very difficult to distinguish which of the above-mentioned processes is acting on the pesticide in the field.

So far, no balance sheet has been proposed by which the contribution of each of these processes could be ascertained. The contribution of each of these processes depends on many factors: microbial activity, physicochemical condition of the soil or water, etc. For example, photodecomposition may be important at the soil surface, with other processes becoming important when the pesticide moves beneath the surface. Hence, an important factor in considering the contribution of the different degradation processes is the time a pesticide remains on the surface versus the time it remains beneath the surface.

Another point about Table 5.1 is that some of the results were obtained in the laboratory under controlled conditions. How important that could be in certain cases in the field is not known. For instance, most of the evidence of photolysis comes from experiments conducted in the laboratory under artificial conditions, generally under mercury lamps emitting principally at 254 mμ. In the few practical experiments carried out in the field, losses of biological activity were proposed to be due to photodecomposition, although the results were affected by other processes: volatility, nonphotochemical hydrolyses, etc. Interpreting the results reported in the table therefore requires care plus knowledge not yet available.

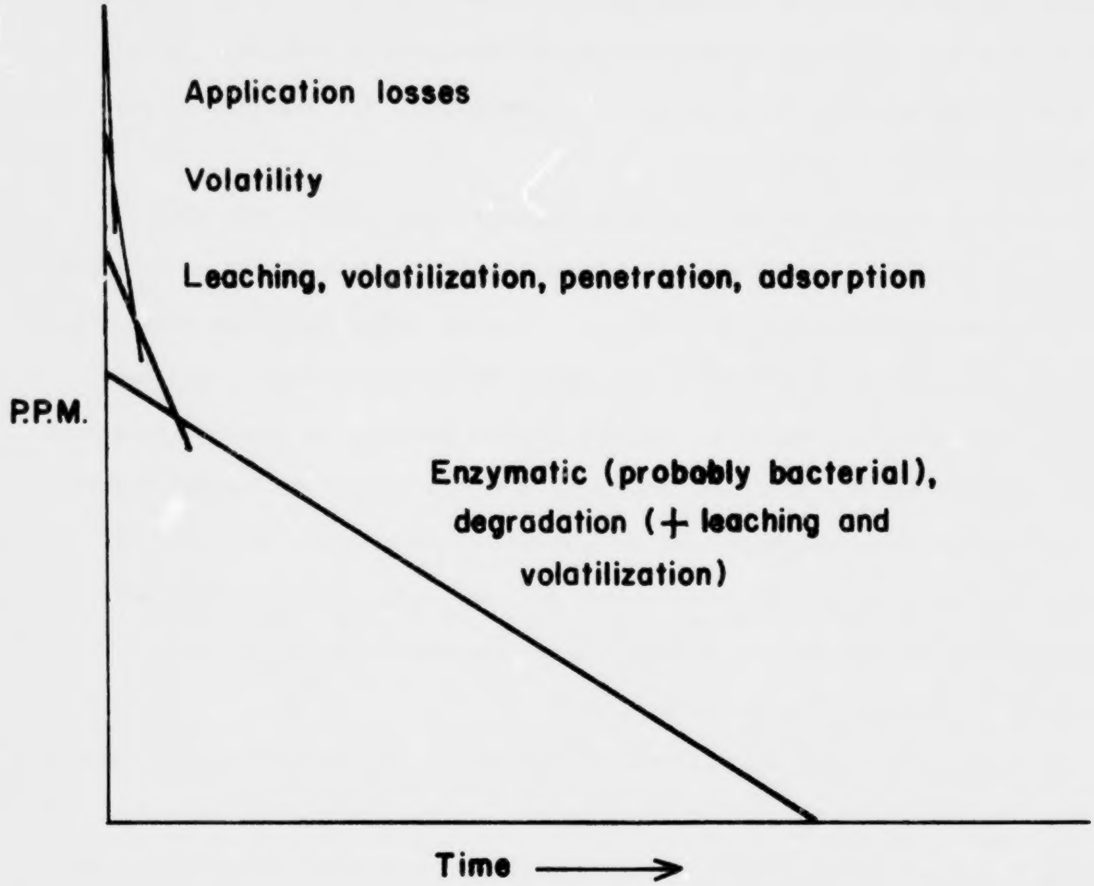
Application losses
Volatility
Leaching, volatilization, penetration, adsorption
P.P.M.
Enzymatic (probably bacterial), degradation (+ leaching and volatilization)
Time →

Figure 5.1 Theoretical breakdown curve for soil insecticides (Edwards, 1966).

Persistence of Pesticides and their Degradation Products

The persistence of pesticides has been studied mainly for two reasons: 1) to see whether effects will be carried over to the next crop; and 2) to see how long the pesticide remains in the soil or water to threaten the terrestrial or aquatic environment. The present study is interested in the second aspect. In study of water pollution, persistence is as important as toxicity. An increase in the persistence and toxicity of a pesticide or its degradation products can damage the aquatic environment.

Persistence depends on many factors: the pesticide itself, soil type, temperature, moisture, air movement, relative humidity, cover crops, microorganisms, application rate, mode of application, etc. Edwards (1966) separated these factors into arbitrary classes of gradually decreasing importance: primary, secondary, tertiary, and quaternary factors. Primary factors include the chemical structure of the pesticide and its intrinsic stability and volatility. Secondary factors include the soil type, which influences adsorption, desorption, and leaching. Tertiary factors include soil temperature, soil moisture, and soil cultivation. Quaternary factors include the formulation and concentration of the pesticide and the soil's mineral content and acidity.

The main processes by which these factors affect the persistence of a pesticide are: decomposition by soil microorganisms, adsorption by soil colloids, leaching, chemical decomposition, volatilization and codistillation, adsorption by plants and other organisms, and soil cultivation. Figure 5.1, from Edwards (1966), shows how these processes influence the decay of soil insecticides at various times of its life. The figure, developed for soil insecticides, can be generalized for all pesticides.

The different processes affecting the persistence of a pesticide are briefly discussed below.

Decomposition by microorganisms: Practically all soils contain microorganisms that are capable of breaking down pesticides (Donaldson, 1968). Optimum conditions of moisture, temperature, aeration, and pH favor intense microbial activity. Since the chemical nature of a pesticide affects the ease with which it is utilized as an energy source by microorganisms, pesticides differ in persistence. Alexander (1965) reported that the microbial degradability of even similar chemicals such as chlorinated phenoxyalkanoates differed with the position of the chlorine atom in the molecule. Kearney and Plimmer (1970) discussed other examples of the relation between chemical structure and persistence or biodegradability.

There has been evidence that repeated applications of pesticides are less stable than the initial application, and this was proposed to be due to adaptation of the chemical by the microorganism, causing later applications of the pesticide to break down in a shorter time (Donaldson, 1968; Aly and Faust, 1964).

Adsorption by soil colloids and sediments: Soil type may be the most important single parameter affecting the adsorption of pesticides to soil (Pierce et al., 1971). Soil type is a very general term, however, neglecting great variability in properties such as content of organic matter, clay content, ion-exchange capacity, surface area, and pH. Generally considered the most important of these various properties for correlation with pesticide adsorption is the content of minerals and organic matter (Pierce et al., 1971). The persistence of a pesticide generally increases with an increase in organic matter (Harris, 1969; Warren, 1954; Lichtenstein et al., 1960; Edwards, 1966) and with an increase in clay content (Warren, 1954). The longer persistence is due to increased adsorption of the pesticide onto the organic matter or clay particles, thus decreasing the availability of the pesticide for microbial decompsoition, volatility, and leaching. However, Hance (1970) in a recent review paper indicated that sorption may increase or reduce the rates of microbial, photochemical, and chemical decomposition of pesticides. He discussed examples of the influence of sorption on each of these processes. According to him, adsorption might be expected to affect microbial activity in one of two conflicting ways. There is likely to be a greater population density of microorganisms on or near soil surfaces than in the soil solution, so it might be expected that adsorption could enhance microbial activity by increasing the concentration of pesticide in areas rich in microorganisms. Conversely, if microorganisms are able to attack pesticides only in solution then adsorption would slow degradation.

Another reason for increased persistence of a pesticide in soils high in organic matter is increased formation of resistant complexes of organic matter and pesticides. Stewart et al. (1971) reported parathion persistence for several years and proposed that parathion formed resistant complexes with the lignin fraction of the soil organic matter. In certain cases organic matter may decrease the persistence time of pesticides (Dubey et al., 1964). Increased microbial activity in soils of high organic matter could increase microbial breakdown of the pesticides (Dubey et al., 1964).

In natural water, adsorption of chemicals by sediments is an important process by which a pesticide disappears from the environment. Krone (1966), from a study of the effect on water quality of sediment inflows to the San Francisco Bay system, reported that the sediments can buffer significant amounts of sorbable material such as heavy metals and pesticides disposed of in the bay. When these sediments, having sorbed toxic compounds, are deposited and not reworked, the sorbed compounds are permanently removed from the water. This finding is supported by recent work of Veith and Lee (1971) who showed that the sorption of toxaphene on lake sediments was irreversible in aqueous solution, and that leaching of appreciable amounts of toxaphene from the sediments by water was highly improbable.

Leaching: Leaching is another process by which a pesticide disappears from the place where applied. The pesticide does not disappear but is transported to another place. Leaching depends on the water solubility of the pesticide, adsorption, and the amount of rainfall or irrigation water applied. Leaching is discussed in detail in the previous chapter.

Chemical decomposition: Like microbial decomposition, chemical decomposition decreases the persistence time of pesticides. For instance, Lichtenstein and Shulz (1964) found that parathion was more persistent in dry soil than in moist soil. They explained this as being due to the hydrolysis of parathion in moist soil.

Volatilization and codistillation: The persistence of a pesticide may also be affected by volatilization and codistillation. This is one of the reasons why a pesticide has a shorter persistence at the soil surface than beneath the surface. Factors affecting volatilization and codistillation are discussed in the previous chapter.

Photodecomposition: Like microbial and chemical decomposition, photodecomposition also affects the persistence of a pesticide. If sunny conditions prevail after a pesticide is applied, photodecomposition can occur at the soil surface before the pesticide is leached into the soil. In the San Joaquin Valley, since large amounts of pesticides are applied during the sunny summer months, certain pesticides may be lost in significant quantities through photodecomposition.

Absorption by plants and other organisms: Uptake by plants and other organisms decreases pesticide concentrations in soil and water, thereby affecting persistence.

Soil cultivation: Lichtenstein and Schulz (1961) found that daily disking of a loam soil decreased the residue levels of DDT and aldrin in soils. They proposed increased volatilization of the insecticides as the cause. Lange et al.

(1971) studied the persistence of herbicides under different cultural practices at the West Side Field Station, in the San Joaquin Valley near Five Points, California. The residual characteristics of some herbicides varied considerably with the different cultural methods. For example, trifluralin showed essentially no residue when applied to the surface and sprinkler-irrigated, but left some residue if mechanically incorporated and then sprinkler- or furrow-irrigated.

The persistence of a pesticide is usually different in water from that in soils. Available data on the persistence of pesticides is limited in natural water as compared with soils. The limited information available indicates that some pesticides have a longer persistence in water than in soils, and some have a shorter. 2,4-D persists longer in natural water than in soils (Aly and Faust, 1964; DeMarco _et al_., 1967; Schwartz, 1967), and many insecticides persist longer in soils than in natural river water (Eichenberger and Lichtenberg, 1971). Pesticides in water, unlike in soils, have high freedom of movement and mixing. When a pesticide is added or transported to water, most of it gets adsorbed to sediments. After adsorption, a small fraction of the pesticide is gradually desorbed and released into the overlying water, where the pesticide concentration is maintained in dynamic equilibrium (Huang, 1971). Studies on major agricultural river basins of California have indicated that an average pesticide concentration of 0.1 to 0.2 ppb in water may mean that bottom sediments contain 20 to 500 ppb (Bailey _et al_., 1967). When a pesticide is added or transported to natural water, the concentrations in the water and in the muds differ greatly in changes over time. The concentration in water may decrease rapidly, whereas the concentration in the bottom mud or sediments may increase for a period and then slowly decrease (Bridges _et al_., 1963).

Generally, the persistence time is lower in water than in the sediments. When 2,4-D is applied to natural water, only 1% remains in the water after a month (House _et al_., 1967), whereas 6% remains in the sediments even after month (House et al., 1967), whereas 6% remains in the sediments even after ten months (Smith and Isam, 1967). Johnson et al. (1966) reported that 3 to 9 years after treatment of eight Wisconsin lakes with 0.1 ppm toxaphene, the levels of toxaphene were 1 to 4 ppb in the water and 0.2 to 1 ppm in the sediments.

From the preceding discussion, it is very clear that the persistence of a pesticide depends on many factors and that differences in these factors from place to place make it impossible to attribute an absolute life to any pesticide. A pesticide will differ drastically in persistence time with different conditions of experiment as reported in the literature. Most cases reported the time required for the disappearance of only a certain percentage of the pesticide initially applied. Because different workers used different bases in measuring the percentages of disappearance, the persistence times of pesticides cannot be compared on a common scale. Also, persistence studies were conducted in different soil types at different application rates, making a valid comparison even more difficult.

Table 5.2 reports the persistence of selected pesticides from the top 100 pesticides used in the San Joaquin Valley. In some of these results, persistence time has been taken as the time required for loss of the phytotoxicity of a herbicide. Loss of phytotoxicity, however, does not necessarily mean that all the herbicide has disappeared. A herbicide may remain in substantial concentration adsorbed to soil colloids and not show phytotoxicity. A pesticide may also have been transported away from the point of application by leaching, runoff, or volatilization. Since the pesticide is not necessarily lost from the environment, persistence time thus calculated should be interpreted with care. Similarly, although pesticides may have low persistence in water, they may persist for a long time adsorbed in the aquatic sediments.

Some persistence results are reported in terms of the half-life of pesticides. Lichtenstein et al. (1971) recently cautioned against the use of halfcides. Lichtenstein et al. (1971) recently cautioned against the use of half-life in pesticide persistence because the rate of decline, which depends on many factors, is not constant at all times. It is usually faster initially than later on. Bro-Rasmussan et al. (1970) also found that the rate of decline of several pesticides decreased irregularly with time.

Persistence of pesticides in soils has been correlated with the chemical character of the pesticide (Kearney et al., 1969; Pierce et al., 1971). Pierce et al. (1971) have separated such compounds into two groups, polar and nonpolar. The polar compounds, estimated not to persist for more than a year, include organophosphates, carbamates, triazines, substituted ureas, and chlorophenoxy compounds. The nonpolar compounds, estimated to persist for 5 to 30 years, include the chloroinated hydrocarbons.

Kearney et al. (1969) related the persistence of several pesticides to their chemical structure (Figure 5.2). That report is the only one we have seen that has compiled the persistence time of several pesticides of varied chemical structures. The persistence time reported was the time that 75 to 100% of the pesticide was lost or the time required for the bioactivity to reach a level of 75 to 100% of the control. The values shown were those resulting from "normal" rates of application and "normal" agricultural conditions. According to them, the data were compiled from a review of approximately eighty sources concerned with pesticide persistence in soils.

The soils of the San Joaquin Valley are loam soils, on average, with about 0.5 to 3% organic matter. These could be considered normal soils, and persistence data from Figure 5.2 and Table 5.2 could be used in the present study.

From the figures and tables on thepersistence of pesticides in soils, it could be seen that, on average, chlorinated hydrocarbon insecticides have the longest persistence (several years), followed by some of the triazine herbicides (one or two years). Organophosphates and carbamates have low persistence.

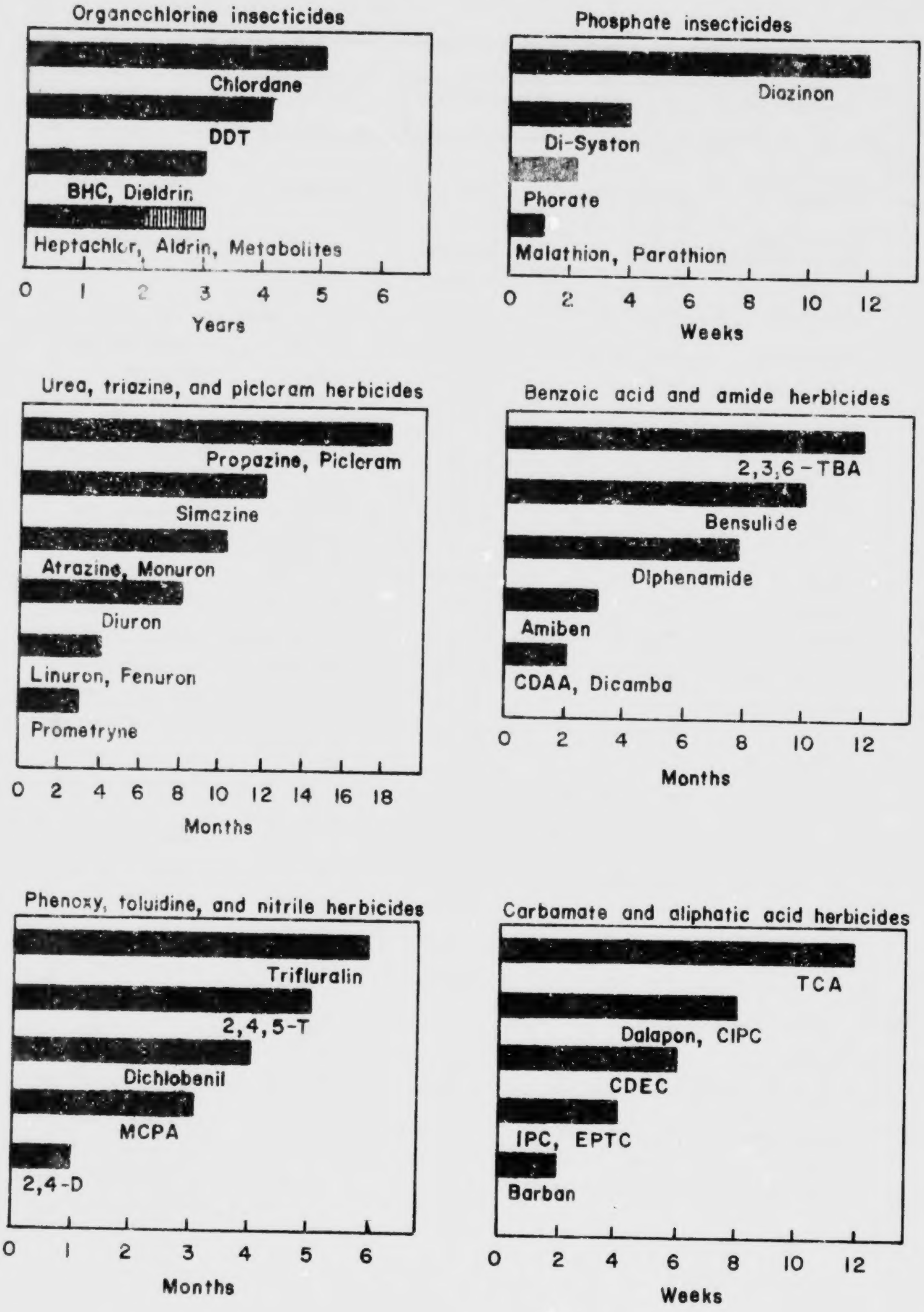

Figure 5.2 Persistence of individual pesticides in soils (Kearney *et al.*, 1969)

Table 5.2 Persistence of Pesticides and Their Degradation Products in Soil and Water

Pesticide and Degradation Products	Application Rate	Type of Soil or Water	Persistence Time	Comments	References
Organochlorine insecticides:					
Chlordane	10 µg/liter	Natural river water	2 to 8 weeks	85% remains	Eichelberger and Lichtenberg (1971)
	Six rates ranging 0.625 to 20 lb/acre	Loam soil	14.3 months	50% remains	Onsager *et al.* (1970)
		Soils	9 to 13 years	25% remains	Stewart and Fox (1971)
	Normal rates	Normal agricultural soils	5 years	25 to 0% remains	Kearney *et al.* (1969)
	10 lb/acre/year	Sandy clay soil	4 years	Half life	Hermanson *et al.* (1971)
	1 to 2 lb/acre	Soils	1 to 6 years	5% remains	Edwards (1966)
DDT	20 lb/acre/year	Sandy clay soil	4 years	Half life	Hermanson *et al.* (1971)
	1 to 2 1/2 lb/acre	Soils	4 to 30 years	5% remains	Edwards (1966)
	10 lb/acre	Silt loam soil	15 years	10.6% remains	Lictenstein *et al.* (1971)
	1 lb/acre	Maine forest soil	9 years	Little lost	Diamond *et al.* (1970)
			30 years	Persistence	Diamond *et al.* (1970)
		Soil	4 years	22% remains	Kroczynski (1968)
	100 ppm	Sandy loam	17 years	39% remains	Nash and Woolson (1967)
	High rate	Soil	3 years	36% remains	Roberts *et al.* (1962)
	Normal	Normal agricultural soils	4 years	25 to 0% remains	Kearney *et al.* (1969)
	10 to 20 lb/acre	Soil	>4 years	Persistence	Clove *et al.* (1961)
	10 to 20 lb/acre	Soil	>10 years	Persistence	Allen *et al.* (1954)
	25 lb/acre	85 soil types	8 years	44% remains	Fleming and Maines (1953)
Endosulfan	2 lb/acre	Soil	96 days	No detectable amounts remain	Dyer *et al.* (1965)
	10 µg/liter	Natural river water	2 weeks	5% remains	Eichelberger and Lichtenberg (1971)
	10 µg/liter	Natural river water	4 weeks	0% remains	Eichelberger and Lichtenberg (1971)
Toxaphene	20 lb/acre/year	Sandy clay soil	4 years	Half life	Hermanson *et al.* (1971)
	140 ppm	Soil	>6 years	Persistence	Westlake and Antonio (1960)
	50 ppm	Sandy loam	11 years	50% remains	Nash and Woolson (1967)
	100 ppm	Sandy loam	14 years	45% remains	Nash and Woolson (1967)
Organophosphorus insecticides:					
Baytex	10 µg/liter	Natural river water	2 weeks	10% remains	Eichelberger and Lichtenberg (1971)
	10 µg/liter	Natural river water	4 weeks	0% remains	Eichelberger and Lichtenberg (1971)
Carbophenothion	2 to 4 lb/acre	Fine sandy soil	6 to 8 months	<5% remains	Mulla *et al.* (1961)
	10 µg/liter	Natural river water	2 weeks	10% remains	Eichelberger and Lichtenberg (1971)
	10 µg/liter	Natural river water	4 weeks	0% remains	Eichelberger and Lichtenberg (1971)

Table 5.2 - Continued

Pesticide and Degradation Products	Application Rate	Type of Soil or Water	Persistence Time	Comments	Reference
Diazinon		Different types of soils	20 weeks	<8% remains	Getzin and Rosefield (1966)
	3 lb/acre	Soil	26 weeks	Persistence	Gunner et al. (1966)
		Soil	≤40 days	Very low levels remain	Malone et al. (1967)
	High application rates	Submerged tropical soil	50 to 70 days	6 to 2% remains	Sethunathan and MacRae (1969)
	Normal	Normal agricultural soils	12 weeks	25 to 0% remains	Kearney et al. (1969)
		Sandy loam soil	1 month	~5% remains	Harris (1970)
	2 Kg/ hectare	Loam soil	10 months	5% remains	Bro-Rasmussen et al. (1970)
	2 to 4 lb/acre	Fine sandy soil	6 to 8 months	<10% remains	Mulla et al. (1961)
Dimethoate	3 μg/liter	Silt loam soil, sandy loam soils	1 month	30% remains	Parker and Dewey (1965)
	2 Kg/ hectare	Loam soil	2 months	25% remains	Bro-Rasmussen et al. (1970)
	4 to 6 lb/acre	Fine sandy soil	2 to 3 months	<10% remains	Mulla et al. (1961)
	10 μg/liter	Natural river water	8 weeks	50% remains	Eichelberger and Lichtenberg (1971)
Ethion	10 μg/liter	Natural river water	8 weeks	50% remains	Eichelberger and Lichtenberg (1971)
	2 to 6 lb/acre	Fine sandy soil	6 to 8 months	43 to 23% remains	Mulla et al. (1961)
Guthion	50 lb/acre	Loam soil	5 months	64 to 13% remains	Schulz et al. (1970)
Malathion	Normal	Normal agricultural soils	1 week	25 to 0% remains	Kearney et al. (1969)
	5 lb/acre	Silt loam soil	8 days	3.1% remains	Lichtenstein and Schulz (1963)
		Soil	2 days	Disappeared from top soil layers	Laygo and Schulz (1963)
	10 μg/liter	Natural river water	2 weeks	10% remains	Eichelberger and Lichtenberg (1971)
	10 μg/liter	Natural river water	4 weeks	0% remains	Eichelberger and Lichtenberg (1971)
Methyl parathion	20 mg/Kg	Sand-clayey soil	7 to 11 days	Complete decomposition	Obuchowska (1967)
	10 μg/liter	Natural river water	2 weeks	10% remains	Eichelberger and Lichtenberg (1971)
	10 μg/liter	Natural river water	4 weeks	0% remains	Eichelberger and Lichtenberg (1971)
Parathion	31.4 lb/acre	Sandy loam soil	4 years	3% remains	Stewart et al. (1971)
	31.4 lb/acre	Sandy loam soil	16 years	0.1% remains	Stewart et al. (1971)
	1 lb/acre	Silty clay loam soil	2 months	No detectable amounts	Knutson et al. (1971)
		Soil	5 years	Persistence	MacPhee et al. (1960)
	5 lb/acre	Silt loam soil	3 months	3% remains	Lichtenstein and Schulz (1965)
	Normal	Normal agricultural soils	1 week	Persistence	Kearney et al. (1968)
		Sandy loam soil	4 weeks	<5% remains	Harris (1970)
	10 μg/liter	Natural river water	4 weeks	<5% remains	Eichelberger and Lichtenberg (1971)
		Water	23 months	Persistence	Muhlmann and Schrader (1957)
Paraoxon	20 ppm	Silt loam soil	1 day	<10% remains	Lichtenstein and Schulz (1965)

Table 5.2 - Continued

Pesticide and Degradation Products	Application Rate	Type of Soil or Water	Persistence Time	Comments	Reference
p-Nitrophenol	20 ppm	Silt loam soil	16 days	No residues detected	Lichtenstein and Schulz (1965)
Aminoparathion	20 ppm	Silt loam soil	2 days	No residues detected	Lichtenstein and Schulz (1965)
Phorate	3 µg/g	Silt loam soil and sandy loam soil	1 month	Complete breakdown	Parker and Deway (1965)
	10 ppm	Sandy loam soil	68 days	50% remains	Way and Scopes (1968)
	Normal	Normal agricultural soils	2 weeks	25 to 0% remains	Kearney *et al.* (1969)
	2 to 8 lb/acre	Sandy loam soil	1 to 2 weeks	<2% remains	Harris (1970)
		Fine sandy soil	2 months	<12% remains	Mulla et al. (1961)
Other insecticides:					
Carbaryl		Water (no mud present)	17 days	50% remains	Karinen *et al.* (1967)
		Water (mud present)	10 days	10% remains	Karinen *et al.* (1967)
Herbicides:					
Amitrole	2 to 10 lb/acre	Moist loam field soil	3 to 5 weeks	Persistence	Klingman (1961)
	1 ppm	Pond water	29 days	8% remains	Grzenda *et al.* (1965)
	1 ppm	Pond water	>201 days	Persistence	Grzenda *et al.* (1966)
		Soil	30 days	20% remains	Ercegovich and Frear (1964)
	20 ppm	Soil	7 weeks	Persistence	Burschel and Freed (1959)
	3 to 18 lb/acre	Soil	1 to 3 months	Residual phytotoxicity	Sheets and Harris (1965)*
	8.9 lb/acre	Soil	4 to 5 months	Residual phytotoxicity	Sheets and Harris (1965)*
Atrazine	2 to 10 Kg/ hectare	Loam soil	4 months	32 to 62% remains	Manorik and Malichauko (1970)
	1 to 100 ppm	Four Hawaiian soils	34 days	15 to 30% remains	Obien and Green (1969)
	1 and 2 lb/acre	Soils	>200 days	Persistence	Isom *et al.* (1970)
	Normal	Normal agricultural soils	10 months	25 to 0% remains	Kearney *et al.* (1969)
	2 lb/acre	Soil	17 months	Persistence	Talbert and Fletchall (1964)
	2 to 4 lb/acre	Soil	4 to 7 months	Residual phytotoxicity	Sheets and Harris (1965)*
	2 to 3 lb/acre	Soil	4 to 7 months	Residual phytotoxicity	Sheets and Harris (1965)*
	3 to 8 lb/acre	Soil	12 months	Residual phytotoxicity	Sheets and Harris (1965)*
	3.2 to 4 lb/acre	Soil	4 to 8 months	Residual phytotoxicity	Sheets and Harris (1965)*
2,4-D	Normal	Normal agricultural soils	1 month	25 to 0% remains	Kearney *et al.* (1969)
	0.5 to 3 lb/acre	Moist loam soil	1 to 4 weeks	Persistence	Klingman (1961)
	4 lb/acre	Peat soils	4 to 18 weeks	Persistence	Hernandez and Warren (1950)
	3.6 lb/acre	Clay loam soil	2 months	Persistence	Agundis (1964)
	10 lb/acre	Several soil types	2 to 14 weeks	Persistence	Akamine (1951)
	1.5 Kg/ hectare	Podzolic soil	2 to 7 weeks	Complete detoxification	Rakitin and Mikhailova (1968)

Table 5.2 - Continued

Pesticide and Degradation Products	Application Rate	Type of Soil or water	Persistence Time	Comments	Reference
	Average	Soil	1 month	Persistence	Sheets and Harris (1965)
	1000 ppm	Water	1 month	1% remains	House et al. (1967)
	1000 ppm	Sediments	10 months	6% remains	Smith and Isom (1967)
	689 to 967 ppm	Water	1 month	1 to 2% remains	Averitt (1967)
	10 ppm	Ponds	6 weeks	Persistence	Cope, Wood and Waller (197
		Lake muds	1 to 2 months	Persistence	Aly and Faust (1964)
		Surface water	>9 weeks	Persistence	Robson (1968)
		Aerobic warm lak water	1 week	Persistence	DeMarco (1967)
		Cold deoxygenated lake water	13 weeks	Persistence	DeMarco (1967)
	4 to 40 lb/acre	Soils	1 month	Residual phytotoxicity	Sheets and Harris (1965)*
	5 lb/acre	Soils	1 month	Residual phytotoxicity	Sheets and Harris (1965)*
Dacthal	Recommended rates	Most soil types	100 days	Average half life	Weed Science Society of America (1970)
Dalapon	50 ppm	43 different California soil	Range from 2 to 8 weeks	Total disappearance to 66% remaining	Day et al. (1965)
		Soils	5 weeks	No phytotoxicity	Sweet et al. (1958)
	50 ppm	Different types of soils (20 to 27% moisture)	4 to 5 weeks	No residue remains	Thiegs (1955)
	50 ppm	Different types of soils (6 to 11% moisture)	14 weeks	Much remains	Thiegs (1955)
	Normal	Normal agricultural soils	8 weeks	25 to 0% remains	Kearney et al. (1969)
	5 to 40 lb/acre	Moist loam field soil	10 to 60 days	Persistence	Klingman (1961)
	7.4 to 20 lb/acre	Soils	1 month	Residual phytotoxicity	Sheets and Harris (1965)*
	20 lb/acre	Soils	3 to 4 months	Residual phytotoxicity	Sheets and Harris (1965)*
	6 to 8 lb/acre	Soils	1 to 2 months	Residual phytotoxicity	Sheets and Harris (1965)*
Diphenamid	Recommended rates	Most soil types	3 to 6 months	Average persistence	Weed Science Society of Americal (1970)
	Normal	Normal agricultural soils	8 months	25 to 0% remains	Kearney et al. (1969)
	3 to 4 lb/acre	Soils	10 to 12 months	Residual phytotoxicity	Sheets and Harris (1965)*
	3 lb/acre	Soils	3 months	Residual phytotoxicity	Sheets and Harris (1965)*
	3.75 lb/acre	Soils	<3 months	Residual phytotoxicity	Sheets and Harris (1965)*
Diuron	Normal	Normal agricultural soils	8 months	25 to 0% remains	Kearney et al. (1969)
	1 to 3 lb/acre	Moist loam field soil	3 to 6 months	Persistence	Klingman (1961)
	10 to 40 lb/acre	Moist loam field soil	6 to 24 months	Persistence	Klingman (1961)

Table 3.2 - Continued

Pesticide and Degradation Products	Application Rate	Type of Soil or Water	Persistence Time	Comments	Reference
	1 to 2 lb/acre	Clay loam and silt loam soils	18 to 20 weeks	Persistence	Bryant and Andrews (1967)
	0.5 to 3 ppm	Pond water	28 days	No detectable residue	McCraren *et al*. (1969)
	3.6 to 4 lb/acre	Soils	5 to 7 months	Residual phyto-toxicity	Sheets and Harris (1965)*
	1 to 2 lb/acre	Soils	4 to 8 months	Residual phyto-toxicity	Sheets and Harris (1965)*
	2 lb/acre	Soils	15 months	Residual phyto-toxicity	Sheets and Harris (1965)*
DNBP	6 to 9 lb/acre	Moist loam field soil	3 to 5 weeks	Persistence	Klingman (1961)
	16 lb/acre	Soil	4 to >8 weeks	Persistence	Warren (1956)
	8 lb/acre	Soil	6 months	Residual phyto-toxicity	Sheets and Harris (1965)*
	12 lb/acre	Soil	>5 months	Residual phyto-toxicity	Sheets and Harris (1965)*
	0.85 lb/acre	Soil	>3 months	Residual phyto-toxicity	Sheets and Harris (1965)*
DNOC	4 Kg/ hectare	Soil	28 weeks	<0.01 ppm remains	Hurle (1968)
	30 ppm	Soil	7 days	Persistence	Bruinsma (1960)
MCPA	1/2 to 3 lb/acre	Moist loam field soil	1 to 4 weeks	Persistence	Klingman (1961)
	Normal	Normal agricultural soil	3 months	25 to 0% remains	Kearney *et al*. (1969)
Paraquat		Pond water	15 days	No residue	Coats *et al*. (1964)
	2.1 to 2.5 ppm	Ponds	6 to 23 days	Persistence	Grzenda *et al*. (1966)
	250 to 2500 ppbw	Reservoirs	13 days	0 to 180 ppbw remains	Yeo (1967)
	1000 to 3000 ppbw	Growth pools	12 days	80 to 300 ppbw remains	Yeo (1967)
Planavin	Recommendation rates	Soils	Moderately persistent		Weed Science Society of America (1970)
Pyrazon	4 ppm	Soil	6 to 7 months	Almost dis-appeared	Horowitz (1968)
	Recommendation rates	Soils	3 to 6 months	Average per-sistence	Weed Science Society of America (1970)
Simazine	3.6 lb/acre	Clay loam soil	60 days	Persistence	Agundis (1964)
	1 to 4 lb/acre	Moist loam field soil	3 to 6 months	Persistence	Klingman (1961)
	10-40 lb/acre	Moist loam field soil	6 to 24 months	Persistence	Klingman (1951)
	2 lb/acre	Soil	17 months	Persistence	Talbert and Fletchall (1964)
		Soil	24 weeks	15% activity remains	Allott (1970)
	3 Kg/ hectare	Soil	11 weeks	Total decomposition	Swietochowski *et al*. (1962)
	Normal	Normal agricultural soil	1 year	25 to 0% remains	Kearney *et al*. (1969)
	2 to 5 lb/acre	Soil	12 months	Residual phyto-toxicity	Sheets and Harris (1965)*
	0.45 to 4.5 lb/acre	Soil	3 to 7 months	Residual phyto-toxicity	Sheets and Harris (1965)*

Table 5.2 - Continued

Pesticide and Degradation Products	Application Rate	Type of Soil or Water	Persistence Time	Comments	Reference
	4 lb/acre	Soil	18 months	Residual phytotoxicity	Sheets and Harris (1965)*
	3.2 to 4.0 lb/acre	Soil	4 to 14 months	Residual phytotoxicity	Sheets and Harris (1965)*
Sodium arsenite	Recommendation rates	Soils	5 years	Phytotoxicity	Weed Science Society of America (1970)
Sodium chlorate	450 to 1200 lb/acre	Moist loam field soil	6 to 12 months	Persistence	Klingman (1961)
	300 lb/acre	Soil	>1 year	Persistence	Nelson (1944)
Butan	Recommendation rates	Several soils	1.5 to 3 weeks	Half life	Weed Science Society of America (1970)
TCA	15 lb/acre	Soil	42 to 64 days	Persistence	Rai and Hammer (1953)
		Soils	5 weeks	No phytotoxicity	Sweet et al. (1958)
	40 to 100 lb/acre	Moist loam field soil	50 to 90 days	Persistence	Klingman (1961)
	Normal	Normal agricultural soil	12 weeks	25 to 0% remains	Kearney et al. (1969)
	8 to 60 lb/acre	Soils	1 to 3 months	Residual phytotoxicity	Sheets and Harris (1965)*
	12.5 to 67 lb/acre	Soils	7 to 12 months	Residual phytotoxicity	Sheets and Harris (1965)*
	16 to 30 lb/acre	Soils	4 months	Residual phytotoxicity	Sheets and Harris (1965)*
Tillam	Recommendation rates	Soil	No injury to subsequent crops		Weed Science Society of America (1970)
Trifluralin	1 and 2 lb/acre	Soils	>200 days	Persistence	Isom et al. (1970)
	0.75 lb/acre	Soils	10 to 12 months	10 to 15% remains	Probst et al. (1967) Weeds (4, (1), 22-6 (1966))
	Normal	Normal agricultural soils	6 months	25 to 0% remains	Kearney et al. (1969)
Other pesticides:					
Captan (fungicide)		Humus sandy soils	3 weeks	Half decay value	Kluge (1969)
	Well distributed in soil	Soil	1 to 2 days	Half life	Griffith and Mathews (1969)
	Added in the form of dressings on the surface of glass beads	Soils	21 days	Little change from the initial concentration	Griffith and Mathhews (1969
		Soil	>65 days	Persistence	Munnecke (1958)
Chloropicrin (fumigant)	100 Kg/hectare	Soil	63 days	10 ppm remains	Tagawa and Tamaru (1969)
	300 Kg/hectare	Soil	160 days	10 ppm remains	Tagawa and Tamaru (1969)
Nabam (fungicide)	100 ppm	Soil	>20 days	Persistence	Domsch (1958)
Ziram (fungicide)		Soil	>35 days	Persistence	Domsch (1958)

*These authors compiled the persistence data from other sources.

Lack of sufficient information presents similar comparisons on the persistence of pesticides in natural water. An insight into the effect of pesticides on the aquatic environment, it is hoped, will result from this information on the persistence of pesticides and their degradation products, together with information in the other chapters on the toxicities of pesticides, amounts used, their ability to move to the aquatic environment, and the ability of organisms to take up these pesticides.

References, Chapter 5

Agundis, O. 1964. The distribution and persistence of simazine and 2,4-D in tropical soils. Abst. Meet. Weed Soc. Amer. p.15-16.

Ahmed, M.K. and J.E. Casida. 1958. Metabolism of some organophosphorus insecticides by microorganisms. J. Econ. Entomol. 51:59-63.

Akamine, E.K. 1951. Persistence of 2,4-D toxicity in Hawaiian soils. Bot. Gaz. (Chicago). 112:312-19.

Alexander, M. 1965. Persistence and biological reactions of pesticides in soils. Soil Sci. Soc. Amer., Proc. 29:1-7.

Allen, N., R.L. Walker, L.C. Fife, R.D. Chisholm, L. Koblitsky, J.F. Bullock, C.R. Hodge, and E.E. Hall. 1954. Persistence of BHC, DDT and toscaphene in soil and the tolerances of certain crops to their residues. Washington, U.S. Dept. of Agriculture. (Tech. Bull. No.1090.)

Allott, D.J. 1970. Herbicide residues. Agr. N. Ireland. 45:30-32.

Aly, O.M. and S.D. Faust. 1964. Studies on the fate of 2,4-D and ester derivatives in natural surface waters. J. Agr. Food Chem. 12:541-46.

Armstrong, D.E., G. Chesters, and R.F. Harris. 1967. Atrazine hydrolysis in soil. Soil Sci. Soc. Amer., Proc. 31:61-66.

Averitt, W.K. 1967. An evaluation of the persistence of 2,4-D amine in surface waters in the State of Louisiana. Proc. S. Weed Conf. 20:342-47.

Bailey, T.E. and J.R. Hannum. 1967. Distribution of pesticides. J. Sanit. Eng. Div., Proc. Amer. Soc. Civil Eng. 93(SA5):27-43.

Banerji, R.C. and N.R. Dhar. 1924. Catalysis. XVII. Temperature coefficients of some dark and light reactions. Z. Anorg. Allg. Chem. 134:172-90.

Baker, R.D. and H.P. Applegate. 1970. Effect of temperature and ultraviolet radiation on the persistence of methylparathion and DDT in soils. Agron. J. 62:509-12.

Bartha, R., H.A.B. Linke, and D. Pramer. 1969. Pesticide conversion to azo compounds by soil microorganisms. Umschau. 69:182-83.

Belser, N.O. and C.E. Castro. 1971. Biodehalogenation - the metabolism of the nematocides cis- and trans-3-chloroallyl alcohol by a bacterium isolated from soil. J. Agr. Food Chem. 19:23-26.

Bollag, J.M., C.S. Helling, and M. Alexander. 1967. Metabolism of 4-chloro-2-methylphenoxyacetic acid by soil bacteria. Appl. Microbiol. 15:1393-98.

Bollag, J.M., C.S. Helling, and M. Alexander. 1968a. 2,4-D metabolism. Enzymatic hydroxylation of chlorinated phenols. J. Agr. Food Chem. 16:826-28.

Bollag, J.M., G.G. Briggs, J.E. Dawson and M. Alexander. 1968b. 2,4-D metabolism. Enzymatic degradation of chlorocatechols. J. Agr. Food Chem. 16:829-33.

Bozarth, G.A., H.H. Funderburk, and E.A. Curl. 1966. Studies on the degradation of 1,1'-dimethyl-4,4'-bipyridinium salt by a soil bacterium. Abstr. Meet. Weed Soc. Amer. p.55.

Brady, U.E., Jr. and B.W. Arthur. 1963. Biological and chemical properties of dimethoate and related derivatives. J. Econ. Entomol. 56:477-82.

Bridges, W.R., B.J. Kallman and A.K. Andrews. 1963. Persistence of DDT and its metabolites in a farm pond. Trans. Amer. Fish. Soc. 92:421-27.

Bro-Rasmussan, F., E. Noddengaard and K. Voldumclausen. 1970. Comparison of the disappearance of eight organophosphorus insecticides from soil in laboratory and in outdoor experiments. Pestic. Sci. 1:179-82.

Bruinsma, J. 1960. The action of 4,6-dinitro-o-cresol (DNOC) in soil. I: The emergency from cress seed in DNOC-treated soil mixtures. Plant Soil. 12:249-58.

Bryant, T.A. and H. Andrews. 1967. Disappearance of diuron, norea, linuron, trifluralin, diphenamid, DCPA and prometryne from the soil. Proc. S. Weed Conf. 20:395-404.

Burschel, P. and V.H. Freed. 1959. The decomposition of herbicides in soil. Weeds. 7:157-61.

Byers, R.A., D.W. Woodham, and M.C. Bowman. 1965. Residues on coastal Bermudagrass, trash and soil treated with granular endosulfan. J. Econ. Entomol. 58:160-61.

Chacko, C.I., J.L. Lockwood, and M. Zabik. 1966. Chlorinated hydrocarbon pesticides: Degradation by microbes. Science. 154:893-95.

Chisaka, H. and P.C. Kearney. 1970. Metabolism of propanil in soils. J. Agr. Food Chem. 18:854-58.

Clore, W.J., W.E. Westlake, K. Walker, and V.R. Boswell. 1961. Residual effects of soil insecticides on crop plants. Pullman, Wash., Washington State University. (Agr. Exp. Sta. Bull. 627).

Coats, G.E., H.H. Funderburk, Jr., J.M. Lawrence, and D.E. Davis. 1964. Persistence of diquat and paraquat in pools and ponds. Proc. S. Weed Conf. 17:308-20.

Colinese, D.L. and H.J. Terry. 1968. Phosalone - a wide spectrum organophosphorus insecticide. Chem. Ind. (London). 1968:1507-11.

Cope, O.B., E.M. Wood, and G.H. Wallen. 1970. Some chronic effects of 2,4-D on the bluegill (Lepomis macrochirus). Trans. Amer. Fish. Soc. 99:1-12.

Couch, R.W., J.V. Gramlich, D.E. Davis and H.H. Funderburk. 1965. The metabolism of atrazine and simazine by soil fungi. Proc. S. Weed Conf. 18:623-31.

Crosby, D.G. 1970. The nonbiological degradation of pesticides in soils. In: Pesticides in the Soil. East Lansing, Mich., Michigan State University. p.86-94.

Crosby, D.G. and E. Leitis. 1964. The photodecomposition of carbamate insecticides. Abstr. Meet. Amer. Chem. Soc. 148:11A.

Crosby, D.G. and M.Y. Li. 1969. Herbicide photodecomposition. In: Degradation of Herbicides. Edited by P.C. Kearney and D.D. Kaufman. New York, Marcel Dekker, Inc. p.321-63.

Crosby, D.G. and H.O. Tutass. 1966. Photodecomposition of 2,4-dichlorophenoxyacetic acid. J. Agr. Food Chem. 14:596-99.

Dahm, P.A. 1970. Chemistry and metabolism of insecticides. In: Agricultural Practices and Water Quality. Edited by T.L. Willrich and G.E. Smith. Ames, Iowa, Iowa State University. p.167-82.

Dalton, R.L., A.W. Evans and R.C. Rhodes. 1966. Disappearance of diuron from cotton field soils. Weeds. 14:31-33.

Day, B.E., L.S. Jordan, and R.C. Russell. 1963. Persistence of dalapon residues in California soils. Soil Sci. 95:326-30.

Demarco, J., J.M. Symons and G.G. Robeck. 1967. Behavior of synthetic organics in stratified impoundments. J. Amer. Water Works Ass. 59:965-76.

Diamond, J.B., G.Y. Belyea and R.E. Kadunce. 1970. DDT residues in robins and earthworms associated with contaminated forest soils. Can. Entomol. 102:1122-30.

Donaldson, T.W. 1968. Persistence of herbicides in the soil. Proc. Victorian Weed Conf., 1st. 7:4-7.

Domsch, K.H. 1958. Die wirkung von Bodenfungiziden. II. Wirkungsdauer. Z. Pflanzenkr. Pflanzenschutz. 65:651-56.

Dubey, H.D. and J.F. Freeman. 1964. Influence of soil properties and microbial activity on the phytotoxicity of linuron and diphenamid. Soil Sci. 97:334-40.

Edwards, C.A. 1966. Insecticide residues in soils. Residue Rev. 13:83-132.

Eichelberger, J.W. and J.J. Lichtenberg. 1971. Persistence of pesticides in river water. Environ. Sci. Technol. 5:541-44.

Engvild, K.C. and H.C. Jensen. 1969. Microbiological decomposition of the herbicide pyrazon. Soil Biol. Biochem. 1:295-300.

Ercegovich, C.D. and D.E.H. Frear. 1964. The fate of 3-amino-1,2,4-triazole in soils. J. Agr. Food Chem. 12:26-29.

Evans, W.C., J.K. Gaunt, and J.J. Davies. 1961. The metabolism of chlorophenoxyacetic acid herbicides by soil microorganisms. Proc. Int. Congr. Biochem, 5th, Moscow. 5:306-7.

Faulkner, J.K. and D. Woodcock. 1964. Metabolism of 2,4-dichlorophenoxyacetic acid ("2,4-D") by Aspergillus niger van tiegh. Nature. 203:865.

Faulkner, J.K. and D. Woodcock. 1965. Fungal detoxification. VII. Metabolism of 2,4-dichlorophenoxyacetic and 4-chloro-2-methylphenoxyacetic acids by Aspergillus niger. J. Chem. Soc. 1965:1187-91.

Fernandez, M. 1966. Identification and toxicity of non-metabolic degradation products of methoxychlor. M.S. Thesis, Univ. of Calif., Davis.

Fernley, H.N. and W.C. Evans. 1959. Metabolism of 2,4-dichlorophenoxyacetic acid by soil pseudomonas: isolation of α-chloromuconic acid as an intermediate. Biochem. J. 73:22.

Fleming, W.E. and W.W. Maines. 1953. Persistence of DDT in soils of the area infested by the Japanese beetle. J. Econ. Entomol. 46:445-49.

Funderburk, H.H., Jr. and G.A. Bozarth. 1967. Review of the metabolism and decomposition of diquat and paraquat. J. Agr. Food Chem. 15:563-67.

Fukuto, T.R. and J.J. Sims. 1971. Metabolism of insecticides and fungicides. In: Pesticides in the Environment. v.1, pt.1. Edited by R. White-Stevens. New York, Marcel Dekker, Inc. p.145-236.

Gaunt, J.K. and W.C. Evans. 1961. Metabolism of 4-chloro-2-methylphenoxyacetic acids by a soil microorganism. Biochem. J. 78:25-26.

Getzin, L.W. and I. Rosefield. 1966. Persistence of diazinon and zinophos in soils. J. Econ. Entomol. 59:512-16.

Golab, T., J.V. Gramlich, and G.W. Probst. 1968. Studies on the fate of diphenamid in soils. Abstr. Meet. Amer. Chem. Soc. 155:A-50.

Graetz, D.A., G. Chesters, T.C. Daniel, L.W. Newland, and G.B. Lee. 1970. Parathion degradation in lake sediments. Water Pollut. Contr. Fed. 42: R76-R94.

Griffith, R.L. and S. Matthews. 1969. The persistence in soil of the fungicidal seed dressings captan and thiram. Ann. Appl. Biol. 64:113-18.

Grzenda, A.R., H.P. Nicholson and W.S. Cox. 1965. The persistance of four herbicides in pond water. Proc. S. Weed Conf. 18:521-32.

Grzenda, A.R., H.P. Nicholson and W.S. Cox. 1966. Persistence of four herbicides in pond water. J. Amer. Water Works Ass. 58:326-32.

Guenzi, W.D. and W.E. Beard. 1968. Anaerobic conversion of DDT to DDD and aerobic stability of DDT in soil. Soil Sci. Soc. Amer., Proc. 32:522-24.

Gunner, H.B., B.M. Zuckerman, R.W. Walker, C.W. Miller, K.H. Deubert and R.E. Longley. 1966. Distribution and persistence of diazinon applied to plant and soil and its influence on rhizosphere and soil microflora. Plant Soil. 25:249-64.

Hamdi, Y.A. and M.S. Tewfik. 1970. Degradation of 3,5-dinitro-o-cresol by Rhizobium and Azotobacter species. Soil Biol. Biochem. 2:163-66.

Hance, R.J. 1970. Influence of adsorption on the decomposition of pesticides. SCI (Soc. Chem. Ind., London) Monogr. 37:92-104.

Harris, C.I. 1965. Hydroxysimazine in soil. Weed Res. 5:275-76.

Harris, C.I., E.A. Woolson and B.E. Humm. 1969. Dissipation of herbicides at three soil depths. Weed Sci. 17:27-31.

Harris, C.R. 1970. Persistence and behavior of soil insecticides. In: Pesticides in the Soil. East Lansing, Mich., Michigan State University. p.58-64.

Hermanson, H.P., F.A. Gunther, L.D. Anderson and M.J. Garber. 1971. Installment application effects upon insecticide residue content of a California soil. J. Agr. Food Chem. 19:722-26.

Hernandez, T.P. and G.F. Warren. 1950. Some factors affecting the rate of inactivation and leaching of 2,4-D in different soils. Proc. Amer. Soc. Hort. Sci. 56:287-93.

Horowitz, M. 1968. Persistence of pyrazon (pyramin) and effects of soil type on its activity. Abstr. Proc. Israel Weed Contr. Conf., 3rd.

House, W.B., L.H. Goodson, H.M. Gadberry and K.W. Kockter. 1967. Assessment of Ecological Effects of Extensive or Repeated Use of Herbicides. Springfield, Va., National Technical Information Service.

Huang, J.C. 1971. Effect of selected factors on pesticide adsorption and desorption in the aquatic system. J. Water Pollut. Contr. Fed. 43:1739-48.

Hurle, K. 1968. Studies on long-term herbicide trials. I. Preliminary report on the degradation of dinitro-o-cresol (DNOC) in the soil after many years' use. Z. Pflanzenkr. (Pflanzenpathol.) Pflanzenschutz., Sonderh. 4:145-46.

Isom, W.H., H.P. Ford, M.P. Lavalleye and L.S. Jordan. 1970. Persistence of herbicides in irrigated soils. Proc. Amer. Calif. Weed Conf. 22:58-63.

Johnson, B.T., R.N. Goodman, and H.S. Goldberg. 1967. Conversion of DDT to DDD by pathogenic and saprophytic bacteria associated with plants. Science. 157:560-61.

Johnson, W.D., G.F. Lee and D. Spyridakir. 1966. Persistence of toxaphene in treated lakes. Air Water Pollut. 10:555-60.

Kallman, B.J. and A.K. Andrews. 1963. Reductive dechlorination of DDT to DDD by yeast. Science. 141:1050-51.

Karinen, J.F., J.G. Lamberton, N.E. Stewart and L.C. Terriere. 1967. Persistence of carbaryl in the marine estuarine environment. Chemical and biological stability in aquarium systems. J. Agr. Food Chem. 15:148-56.

Kaufman, D.D. 1970. Pesticide metabolism. In: Pesticides in the Soil. East Lansing, Mich., Michigan State University. p.72-85.

Kaufman, D.D. and J. Blake. 1970. Degradation of atrazine by soil fungi. Soil Biol. Biochem. 2:73-80.

Kearney, P.C. 1966. Metabolism of herbicides in soils. Advan. Chem. Ser. 60:250-62.

Kearney, P.C., and C.S. Helling. 1969. Reactions of pesticides in soils. Residue Rev. 25:25-44.

Kearney, P.C. and D.D. Kaufman. 1969. Degradation of Herbicides. New York, Marcel Dekker, Inc.

Kearney, P.C., D.D. Kaufman and M.L. Beall, Jr. 1964a. Enzymatic dehalogenation of 2,2-dichloropropionate. Abstr. Meet. Weed Soc. Amer. p.13.

Kearney, P.C., D.D. Kaufman and M.L. Beall, Jr. 1964b. Enzymatic dehalogenation of 2,2-dichloropropionate. Biochem. Biophys. Res. Commun. 14:29-33.

Kearney, P.C., D.D. Kaufman and T.J. Sheets. 1965. Fungal metabolism of herbicides, metabolites of simazine by Aspergillus fumigatus. J. Agr. Food Chem. 113:369-72.

Kearney, P.C. and J.R. Plimmer. 1970. Relation of structure to pesticide decomposition. In: Pesticides in the Soil. East Lansing, Mich., Michigan State University. p.65-71.

Kearney, P.C., E.A. Woolson, J.R. Plimmer and A.R. Isensee. 1969. Decontamination of pesticides in soils. Residue Rev. 29:137-50.

Keil, J.E. and L.E. Priester. 1969. DDT uptake and metabolism by a marine diatom. Bull. Environ. Contam. Toxicol. 4:169.

Klingman, G.C. 1961. Weed Control: As a Science. New York, Wiley.

Kluge, E. 1969. Duration of the effect of thiuram, ferbam and captan in forest soils. Arch. Pflanzenschutz. 5:39-53.

Knutson, H., A.M. Kadoum, T.L. Hopkins, G.F. Swoyer and T.L. Harvey. 1971. Insecticide usage and residues in a newly developed great plains irrigation district. Pestic. Monit. J. 5:17-27.

Koivistoinen, P. 1962. Effect of sunlight on the disappearence of parathion residues. Acta Agr. Scand. 12:285-97.

Konrad, J.G., D.E. Armstrong, and G. Chesters. 1967. Soil degradation of diazinon, a phosphorothioate insecticide. Agron. J. 59:591-94.

Konrad, J.G., G. Chesters, and D.E. Armstrong. 1969. Soil degradation of malathion, a phosphorodithionate insecticide. Soil Sci. Soc. Amer., Proc. 33:259-62.

Kroczynski, J. 1968. Studies on residues of DDT, Lindane and DMDT in soil. Biul. Inst. Ochr. Rosl. 41:75-83

Krone, R.B. 1966. Predicted suspended sediment inflows to the San Francisco Bay System. Prepared for Central Pacific River Basins Project. San Francisco, Federal Water Pollution Control Administration, Southwest Region.

Lange, A.H., B.B. Fischer and R. Hoover. 1971. Herbicide residues under different cultural practices. Calif. Agr. 25:13-14.

Laygo, E.R. and J.T. Schulz. 1963. Persistence of organophosphate insecticides and their effects on microfauna in soils. Proc. N. Dak. Acad. Sci. 17:64-65.

Lichtenstein, E.P. and K.R. Schulz. 1961. Effect of soil cultivation, soil surface and water on the persistence of insecticidal residues in soils. J. Econ. Entomol. 54:517-22.

Lichtenstein, E.P. and K.R. Schulz. 1964. The effect of moisture and microorganisms on the persistence and metabolism of some organophosphorus insecticides in soils, with special emphasis on parathion. J. Econ. Entomol. 57:618-27.

Lichtenstein, E.P., T.W. Fuhremann, and K.R. Schulz. 1971. Persistence and vertical distribution of DDT, lindane and aldrin residues, 10 and 15 years after single soil application. J. Agr. Food Chem. 19:718-21

Lichtenstein, E.P., L.J. DePew, E.L. Eshbaugh and J.P. Seesman. 1960. Persistence of DDT, aldrin and lindane in some midwestern soils. J. Econ. Entomol. 53:136-42.

Lichtenstein, E.P., K.R. Schulz, R.F. Skrentny, and Y. Tsukano. 1966. Toxicity and fate of insecticide residues in water. Arch. Environ. Health. 12:199-212.

Linke, H.A.B. 1970. 3,3',4'-Trichloro-4-(3,4-dichloroanilino) azobenzene, a degradation product of the herbicide propanil, in soil. Naturwissenschaften. 57:307-8.

Liu, S. and J. Bollag. 1971. Metabolism of carbaryl by a soil fungus. J. Agr. Food Chem. 19:487-90.

Loos, M.A., J.M. Bollag and M. Alexander. 1967. Phenoxyacetate herbicide detoxication by bacterial enzymes. J. Agr. Food Chem. 15:858-60.

Lopez-Gonzalez, J.D. and C. Valenzuela-Calaharro. 1970. Associated decomposition of DDT to DDE in the diffusion of DDT on homoionic clays. J. Agr. Food Chem. 18:520-23.

Ludwig, R.A. and G.D. Thorn. 1960. Chemistry and mode of action of dithiocarbamate fungicides. In: Advances in Pest Control Research. v.3. Edited by R.L. Metcalf. New York, Interscience Publ., Inc. p.219-52.

MacPhee, A.W., D. Chisholm and C.R. MacEachern. 1960. The persistence of certain pesticides in the soil and their effect on crop yields. Can. J. Soil Sci. 40:59-62.

Malone, C.R., A.G. Winnett and K. Helrich. 1967. Insecticide-induced responses in an oil field ecosystem: persistence of diazinon in the soil. Bull. Environ. Contam. Toxicol. 2:83-89.

Manorik, A.V. and S.M. Malichenko. 1970. Role of soil and plants in the inactivation of simazine and atrazine. Agrokhimiya. 9:114-19.

Matsumura, F. and G. Boush. 1966. Malathion degradation by Trichoderma viride and a pseudomonas species. Science. 153:1278-80.

Matsumura, F. and G.M. Boush. 1968. Degradation of insecticides by a soil fungus, Trichoderma viride. J. Econ. Entomol. 61:610-12.

Matsumura, F., K.C. Patil and G.M. Boush. 1971. DDT metabolized by microorganisms from Lake Michigan. Nature. 230:325-26.

Mattson, A.M., J.T. Spillane and G.W. Pearce. 1955. Organophosphorus insecticides. Dimethyl 2,2-dichlorovinyl phosphate (DDVP), an organophosphorus compound highly toxic to insects. J. Agr. Food Chem. 3:319-21.

McCraven, J.P., O.B. Cope, and L. Eller. 1969. Some chronic effects of diuron on bluegills. Weed Sci. 17:497-504.

Menzie, C.M. 1969. Metabolism of Pesticides. U.S. Dept. of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife. (Washington, Govt. Print. Off.)

Metcalf, R.L., T.R. Fukuto, and M.Y. Winton. 1963. Chemical and biological behavior of fenthion residues. Bull. W.H.O. 29:219-26.

Mick, D.L. and P.A. Dahm. 1970. Metabolism of parathion by two species of Rhizobium. J. Econ. Entomol. 63:1155-59.

Miller, C.W., B.M. Zuckerman, and A.J. Charig. 1966. Water translocation of diazinon-C^{14} and parathion-S^{35} off a model cranberry bog and subsequent occurrence in fish and mussels. Trans. Amer. Fish. Soc. 95:345.

Miskus, R.P., D.P. Blair and J.E. Casida. 1965. Insecticide metabolism. Conversion of DDT to DDD by bovine rumen fluid, lake water, and reduced porphyrius. J. Agr. Food Chem. 13:481-83.

Mitchell, T.H., J.H. Ruzicka, J. Thomson, and B.B. Wheals. 1968. The chromatographic determination of organophosphorus pesticides. Part III. The effect of irradiation on the parent compounds. Chromatog. 32:17-23.

Miyazaki, S., G.M. Boush, and F. Matsumura. 1970. Microbial degradation of chlorobenzilate (ethyl 4,4'-dichlorobenzilate) and chloropropylate (isopropyl 4,4'-dichlorobenzilate). J. Agr. Food Chem. 18:87-91.

Moje, W., D.E. Munnecke and L.T. Richardson. 1964. Carbonyl sulphide, a volatile fungitoxicant from nabam in soil. Nature. 202:831-32.

Mosier, A.R., W.D. Guenzi and L.L. Miller. 1969. Photochemical decomposition of DDT by a free-radical mechanism. Science. 164:1083-85.

Muhlmann, R. and G. Schrader. 1957. Hydrolase der insektiziden phosphorsäurester. Z. Naturforsch. B. 12:196-208.

Mulla, M.S., G.P. Georghiou, and H.W. Cramer. 1961. Residual activity of organophosphorus insecticides in soil as tested against the Eye Gnat, Hippelates collusor. J. Econ. Entomol. 54:865-70.

Munnecke, D.E. 1958. Persistence of nonvolatile diffusible fungicides in soil. Phytopathology. 48:581-85.

Munnecke, D.E., K.H. Domsch, and J.W. Eckert. 1962. Fungicidal activity of air passed through columns of soil treated with fungicides. Phytopathology. 52:1298-1306.

Nelson, R.T. 1944. Studies on microbial activity, chlorate reduction and chlorate toxicity in soils treated with sodium chlorate. J. Agr. Res. 68:221-37.

Nash, R.G. and E.A. Woolson. 1967. Persistence of chlorinated hydrocarbon insecticides in soils. Science. 157:924-27.

Obien, S.R. and R.E. Green. 1969. Degradation of atrazine in four Hawaiian soils. Weed Sci. 17:509-14.

Obuchowska, I. 1967. Stability of organophosphorus pesticides (methyl parathion) in soils. Rocz. Panstu. Zakl. Hig. 18:655-59.

Onsager, J.A., H.W. Rusk and L.I. Butler. 1970. Residues of aldrin, dieldrin, chlordane, and DDT in soil and sugar beets. J. Econ. Entomol. 63:1143-46.

Parker, B.L. and J.E. Deway. 1965. Decline of phorate and dimethoate residues in treated soils based on toxicity to Drosophila melanogaster. J. Econ. Entomol. 58:106-11.

Plimmer, J.R., P.C. Kearney, D.D. Kaufman, and F.S. Guardia. 1967. Amitrole decomposition by free radical-generating systems and by soils. J. Agr. Food Chem. 15:996-99.

Plimmer, J.R., P.C. Kearney, H. Chisaka, Y.B. Yount and U.I. Klingebiel. 1970. 1,3-Bis(3,4-dichlorophenyl) triazine from propanil in soils. J. Agr. Food Chem. 18:859-61.

Probst, G.W. and J.B. Tepe. 1969. Trifluralin and related compounds. In: Degradation of Herbicides. Edited by P.C. Kearney and D.D. Kaufman. New York, Marcel Dekker, Inc. p.255-82.

Probst, G.W., T. Golab, R.J. Herberg, F.J. Holzer, S.J. Parka, C. Van der Schans and J.B. Tepe. 1967. Fate of trifluralin in soils and plants. J. Agr. Food Chem. 15:592-99.

Pierce, R.H., Jr., C.E. Olney and G.J. Felback, Jr. 1971. Pesticide adsorption in soils and sediments. Eviron. Letters. 1:157-72.

Rai, G.S. and C.L. Hamner. 1953. Persistence of sodium trichloroacetate in different soil types. Weeds. 2:271-79.

Rakitin, Y.B. and T.P. Mikhailova. 1968. Detoxication of 2,4-D in dernopodzolic soil. Agrokhimiya. 4:118-22.

Roberts, J.E., R.D. Chisholm and L. Koblitsky. 1962. Persistence of insecticides in soil and their effects on cotton in Georgia. J. Econ. Entomol. 55:153-55.

Robson, T.O. 1968. Some studies of the persistence of 2,4-D in natural surface waters. Proc. Brit. Weed Contr. Conf., 9th. p.404-8.

Rosen, J.D. 1967. The photolysis of diphenamid. Bull. Environ. Contamin. and Toxicol. 2:349-54.

Russell, J.D., M. Cruz, J.L. White, G.W. Baily, W.R. Payne, Jr., J.D. Pope, Jr., and J.I. Teasley. 1968. Mode of chemical degradation of s-triazine by montmorillonite. Science. 160:1340-42.

Sandi, E. 1958. Reduction of parathion induced by light. Nature. 181:499.

Schulz, K.R., E.P. Lichtenstein, T.T. Liang, and T.W. Fuhremann. 1970. Persistence and degradation of azinphosmethyl in soils as affected by formulation and mode of application. J. Econ. Entomol. 63:432-38.

Schwartz, H.G., Jr. 1967. Microbial degradation of pesticides in aqueous solution. J. Water Pollut. Contr. Fed. 39:1701-14.

Sethunathan, N. and I.C. MacRae. 1969. Persistence and biodegradation of diazinon in submerged soils. J. Agr. Food Chem. 17:221-25.

Sethunathan, N. and T. Yoshida. 1969. Fate of diazinon in submerged soil. Accumulation of hydrolysis product. J. Agr. Food Chem. 17:1192-95.

Sheets, T.J. and C.I. Harris. 1965. Herbicide residues in soils and their phytotoxicities to crops grown in rotation. Residue Rev. 11:119-140.

Skinner, W.A., D.E. Stallard and W.E. Priddle. 1964. The isolation and identification of the metabolites of dacthal herbicide. Abstr. Meet. Amer. Chem. Soc. 147:A4-5.

Skipper, H.D., C.M. Gilmour and W.R. Furtick. 1967. Microbial versus chemical degradation of atrazine in soils. Soil Sci. Soc. Amer., Proc. 31:653-56.

Slade, P. 1965. Photochemical degradation of paraquat. Nature. 207:515-16.

Smith, G.E. and B.G. Isom. 1967. Investigation of effects of large-scale applications of 2,4-D on aquatic fauna and water quality. Pestic. Monit. J. 1:16-21.

Smith, D.T. and W.F. Meggitt. 1970. Persistence and degradation of pyrason in soil. Weed Sci. 18:260-64.

Steenson, T.I. and N. Walker. 1956. Observations on the bacterial oxidation of chlorophenoxyacetic acids. Plant Soil. 8:17-32.

Steenson, T.I. and N. Walker. 1957. The pathway of breakdown of 2,4-dichloro- and 4-chloro-2-methyl phenoxyacetic acid by bacteria. J. Gen. Microbiol. 16:146-54.

Stewart, D.K.R. and C.J.S. Fox. 1971. Persistence of organochlorine insecticides and their metabolites in Nova Scotian soils. J. Econ. Entomol. 64:367-71.

Stewart, D.K.R., D. Chisholm and M.T.H. Ragab. 1971. Long term persistence of parathion in soil. Nature. 229:47.

Sweet, R.D., L. Feddema, G. Crabtree and D. Baker. 1958. Longevity of several herbicides in soils. Proc. Northeast. Weed Contr. Conf. 15:17-24.

Swietochowski, B., H. Zurawski, and J. Piss. 1962. The effect of environment on herbicides added to the soil. I. The rate of simazine decomposition in the soil. Zesz. Nauk. Wyzsz. Szk. Roln. Wroclawiu, Roln. 15:73-82.

Tagawa, H. and K. Tomaru. 1969. Soil sterilization with fumigants. 2. Factors that affect the amount of chloropicrin residues in soil. Bull. Hatano. Tols. Exp. Sta. 65:85-91.

Talbert, R.D. and O.H. Fletchall. 1964. Inactivation of simazine and atrazine in the field. Weeds. 12:33-37.

Tewfik, M.S. and W.C. Evans. 1966. The metabolism of 3,5'dinitro-o-cresol (DNOC) by soil microorganisms. Biochem. J. 99:31-32.

Thiegs, B.J. 1955. The stability of dalapon in soils. Down to Earth. 11:2-4.

Thomason, I.J., C.E. Castro, R.C. Baines and R. Mankau. 1971. What happens to soil fumigants after nematode control? Calif. Agr. 25:10-12.

Veith, G.D. and G.F. Lee. 1971. Water chemistry of toxaphene-role of lake sediments. Environ. Sci Technol. 5:230-34.

Ware, G.W. and C.C. Roan. 1971. Interaction of pesticides with aquatic microorganisms and plankton. Residue Rev. 33:15-45.

Warren, G.F. 1954. Rate of leaching and breakdown of several herbicides in different soils. Proc. N. Central Weed Contr. Conf. 11:5-6.

Warren, G.F. 1956. Weed control in transplanted tomatoes. Proc. N. Central Weed Contr. Conf. 13:149-50.

Way, M.J. and N.E.A. Scopes. 1968. Persistence and effects on soil fauna of some soil applied systemic insecticides. Ann. Appl. Biol. 62:199-214.

Wedemeyer, G. 1966. Dechlorination of DDT by *Aerobacter aerogenes*. Science. 152:647.

Weed Society of America. 1970. *Herbicide Handbook of the Weed Science Society of America*. Urbana, Ill., The Society. (WSSA Monogr. 3).

Westlake, W.E. and J.B. San Antonio. 1960. Insecticide residues in plants, animals and soils. *In*: *The Nature and Fate of Chemicals Applied to Soils, Plants, and Animals*. Washington, U.S. Dept. of Agriculture. (ARS 20-29). p.105-15.

Williams, A.K., S.T. Cox and R.G. Eagon. 1965. Conversion of 3-amino-1,2,4-triazole into 3-amino-1,2,4-triazolyl alanine and its incorporation into protein by *Escherichia coli*. Biochem. Biophys. Res. Commun. 18:250-54.

White-Stevens, R. 1971. *Pesticides in the Environment*. Volume 1, Part 1, New York, Marcel Dekker, Inc.

Yeo, R.R. 1967. Dissipation of diquat and paraquat and effects on aquatic weeds and fish. Weeds. 15:42-46.

Zayed, S.M.A.D., A. Hassan, and T.M. Hussein. 1965a. Organophosphorus insecticides. II. Distribution and metabolism of 0,0-dimethyl-2,2,2-trichloro-1-methoxy-ethyl phosphonate-^{32}P in the adult larva of *Prodenia litura*. Z. Naturforsch. B. 20:587-91.

Zayed, S.M.A.D., I.Y. Mastafa, and A. Hassan. 1965b. Metabolism of organophosphorus insecticides. VII. Transformation of ^{32}P-labeled dipterex through microorganisms. Archiv. Mikrobiol. 51:118-21.

CHAPTER 6

IMPACT OF PESTICIDE POLLUTION ON THE AQUATIC ENVIRONMENT

As mentioned previously, pesticides are applied in large quantities to control hundreds of pests on scores of crops throughout the San Joaquin Valley. The movement of these chemicals through the ecosystem and their ultimate fate is poorly understood.

Preceding chapters have discussed possible routes of movement of pesticides, the degradation and metabolic products of individual pesticides, and the persistence of these compounds in the environment. All of this information is necessary for evaluation of the hazard or safety associated with the use of a particular chemical. Specifically, these factors determine the concentrations of a pesticide and its by-products that are found at a given time following its application.

Calculating the probable concentration of a compound in a particular environment, although highly desirable, is not sufficient to predict what effects that compound may have on the natural environment; it is also necessary to know how various concentrations alter the biological community. This chapter discusses information currently available on pesticide-organism interactions in the aquatic environment. More important, it indicates information that is still lacking. Much basic ecological research is still needed before a predictive model can be fully developed.

Aquatic Ecosystems In The San Joaquin Valley

There are many and diverse bodies of water within the eight-county area considered in this study. Many important waterways in the area are man-made, including irrigation ditches and canals, numerous reservoirs, and the California aqueduct. The natural and man-made ecosystems range in size from small vernal ponds to impoundments such as the San Luis Reservoir, and from intermittent creeks to the San Joaquin River. The fish habitat exceeds 6,000 miles of streams and canals and 59,000 acres of lakes and reservoirs that support both cold-water and warm-water species (California Fish and Game, 1965). The varied habitats are certainly occupied by different species assemblages, though the biological components of these environments have seldom been investigated. We are not aware of any recent publications about aquatic communities in the San Joaquin Valley. We present here a general introduction to aquatic communities, because a specific description is impossible at this time.

Biological Communities in Aquatic Environments

The impact of an alteration to any system can be assessed only after one understands how the system functions. Therefore, the nature of aquatic ecosystems is briefly discussed before we consider the effect of pesticides in these environments.

Many ecology textbooks discuss the nature of biological communities. More comprehensive treatment of the structure and function of ecosystems can be found in Allee *et al*. (1949), Odum (1959), or Smith (1966). Aquatic communities have received special attention in texts by Reid (1961), Ruttner (1953), and Warren (1971), and "The Dynamics of Aquatic Ecosystems" were recently reviewed by Mann (1969). These sources were consulted in preparing the following description.

Figure 6.1 diagrams some structure and important relation in ecosystems. Such presentations disregard the specific differences actually found in natural communities. Every localized community is different from any other community, although the types of organisms found are quite characteristic whenever environmental conditions are similar. Different habitats have characteristically different types of organisms. Furthermore, the fundamental differences between

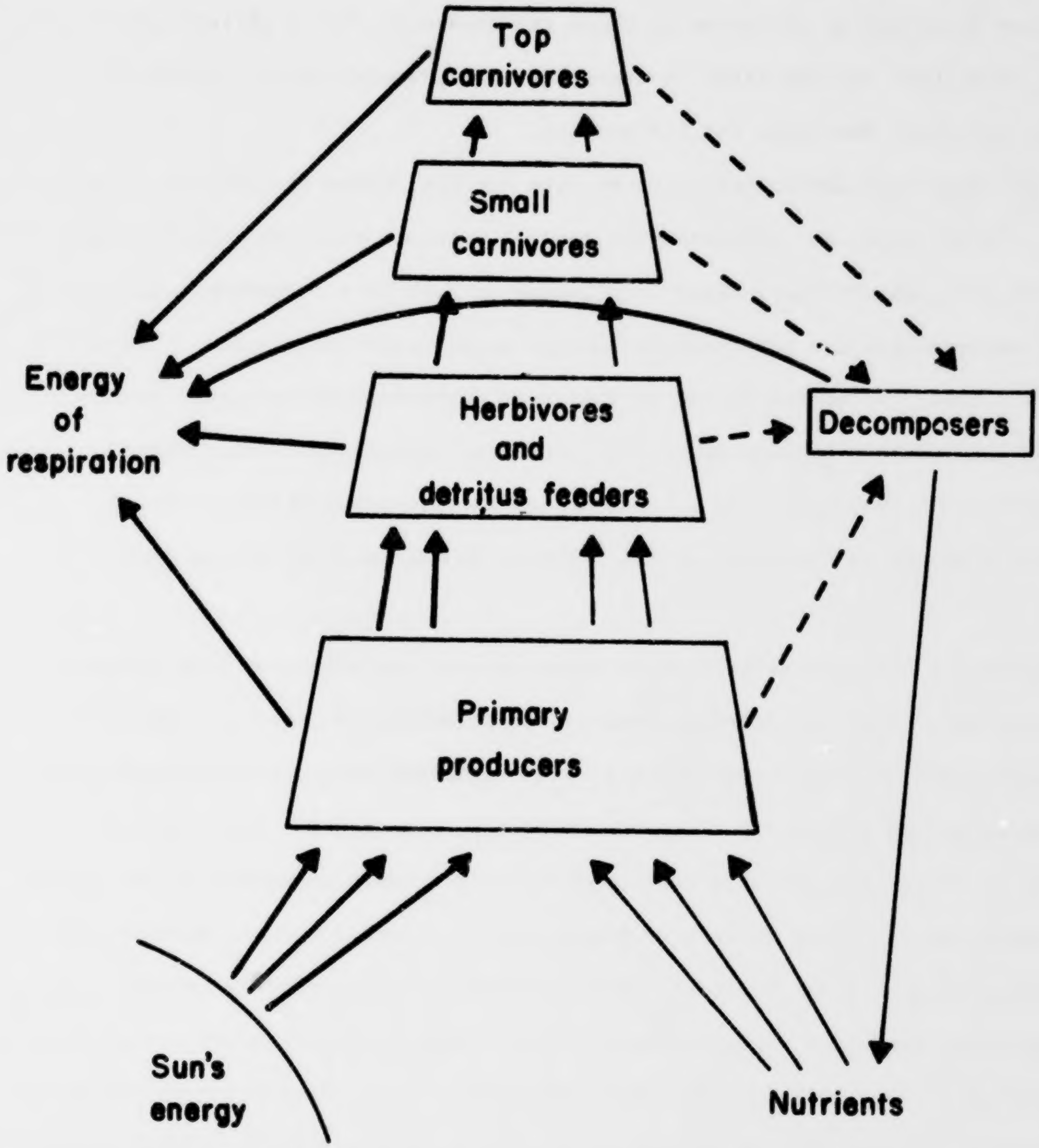
Top carnivores
Small carnivores
Energy of respiration
Herbivores and detritus feeders
Decomposers
Primary producers
Sun's energy
Nutrients

Figure 6.1 Generalized Relationships of Ecosystems (from Mann, 1969)

lentic and lotic environments are significant in determining the effects of particular chemicals on the biota of these environments. These differences must be taken into consideration in assessing environmental impact, although they are not fully discussed in this section.

Lakes have been subdivided into the lake surface, limnetic zone, littoral zone, profundal zone, and submersed structures. Streams could be regarded similarly but are classified primarily with regard to flow rate. Fundamentally, aquatic environments are populated by benthic populations and planktonic populations. These can be considered as different population assemblages, despite numerous interactions between species in these two assemblages. For example, fish populations prey upon both planktonic and benthic populations, sometimes switching from one to the other as the relative abundance of food organisms changes.

Figure 6.1 divides the biological components of the ecosystem into primary producers, herbivores and detritus feeders, small carnivores, top carnivores, and decomposers. Primary producers are those organisms that can photosynthesize, using solar energy to convert inorganic nutrients into organic compounds that serve as an energy source for animal populations. Primary producers in the aquatic environment can be algae, mosses, or higher plants. Herbivores are animals that feed primarily upon plant material. Detritus feeders are primarily benthic organisms that feed upon organic matter in the sediments. Carnivores are animals that prey upon other animals. The interrelations between carnivore populations are not well defined, but top carnivores are those species with no natural predator in the ecosystem under consideration. In fresh-water ecosystems the top carnivores are usually fish, though some species of fish are not top carnivores. Decomposers serve a vital function in ecosystems. Dead organisms or parts thereof, feces, and other material excreted from all the other groups are used as an energy source by the decomposers. In the process they convert organic matter back into nutrients to be used by the primary producers. Some materials are decomposed by metabolic processes and excreted, but most decomposition is thought to result from fungi and bacteria. Mann (1969) indicates that almost nothing is known about the signficance of decomposers.

Figure 6.1 indicates two important processes: the flow of energy; and the cycling of matter. As mentioned, the sun is a source of energy for primary producers, whereas all other groups acquire energy by eating something. Consequently, the upper levels of the food chain can be maintained only if the lower levels are continually replenished. Primary production (photosynthesis) is the only means of replenishment, so the structure of the entire ecosystem is intimately tied to primary production. An especially important consideration with regard to pesticides is the circulation of matter. Matter, unlike energy, is not lost from ecosystems but is transferred from one species to another in the food chain. If a prey species contains some toxic material, this is taken in by the predator and can be lost by either degradation or excretion. Toxic materials can thus be stored and accumulated by higher levels of the food chain, leading to biomagnification (discussed later).

This very general introduction, it is hoped, will be sufficient for understandin the functioning of ecosystems. The following description of aquatic ecosystems is primarily a listing of the types of organisms that are most common.

Planktonic populations include phytoplankton and zooplankton, as well as bacterial and fungal decomposers. Phytoplankton, whose primary function is photosynthesis, are usually green or blue-green algae, although diatoms are very important in some environments. The phytoplankton are preyed upon by zooplankton species, which may be protozoans, rotifers, or crustaceans. Frequently an environment will have three dominant zooplankton species, a rotifer, a cladoceran, and a copepod, as well as several less important species. Protozoans and rotifers may be preyed upon by larger zooplankton, but fish are the major predator of all these groups. Plankton populations are more characteristic of lakes and ponds, but are also found in some large, slow rivers.

Benthic populations are characteristic of both flowing and standing waters. Filamentous and attached unicellular algae are frequently present in the euphotic zone. In some environments this zone may also contain mosses as well as submerged or emergent vacular plants. Benthic fauna consists primarily of annelids, immature insects, and crustaceans (amphipods and crayfish). Other taxonomic groups, especially ostracods and nematodes, are present in great abundance in some environments, but their significance is largely undetermined. A major source of energy for benthic populations is the detritus that falls when plankton individuals die. This detritus is also the major substrate for decomposers in the sediment.

Standing waters often have free-floating vascular plants. Any plant group may be the major primary producer, depending on the particular environment.

In addition most fresh-water ecosystems have some fish species that prey upon the other populations. Table 6.1 lists the major types of organisms that a pesticide may affect in fresh-water aquatic ecosystems as discussed above.

Table 6.1 - Major Biological Components of Aquatic Ecosystems

Primary producers:	Consumers:	Decomposers:
Phytoplankton Attached filamentous algae Higher plants -submerged -emergent -floating	Zooplankton -protozoa -rotifers -crustacea Benthic invertebrates -annelids -insects -crustacea -molluscs	Fungi (in water column and sediments) Bacteria (in water column and sediments)

Figures 6.2 through 6.4 are representations of aquatic communities studied

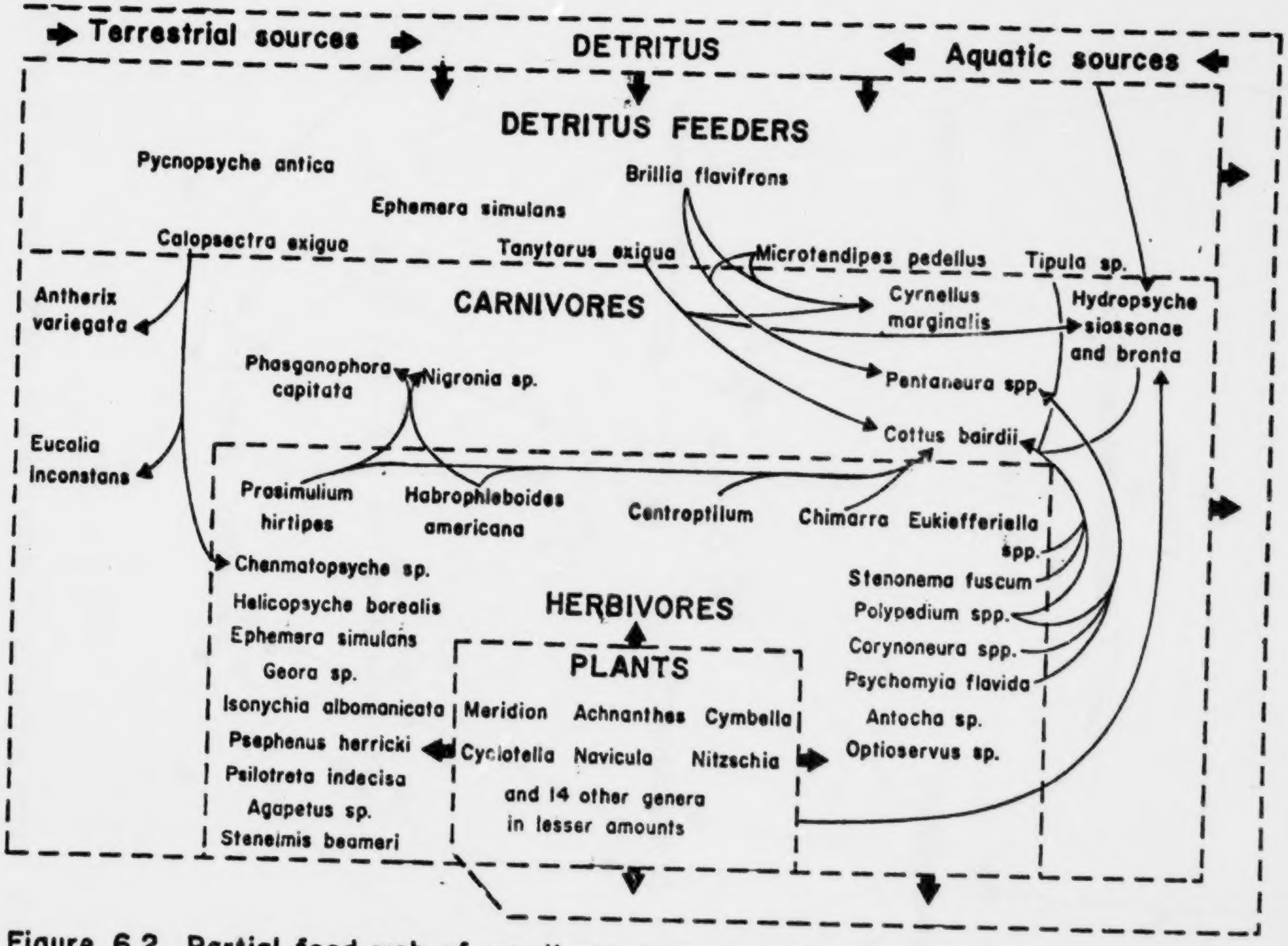
Terrestrial sources
DETRITUS
Aquatic sources
DETRITUS FEEDERS
Pycnopsyche antica
Brillia flavifrons
Ephemera simulans
Calopsectra exigua
Tanytarus exigua
Microtendipes pedellus
Tipula sp.
CARNIVORES
Antherix variegata
Cyrnellus marginalis
Hydropsyche siossonae and bronta
Phasganophora capitata
Nigronia sp.
Pentaneura spp.
Eucalia inconstans
Cottus bairdii
Prosimulium hirtipes
Habrophleboides americana
Centroptilum
Chimarra
Eukiefferiella spp.
Chenmatopsyche sp.
Stenonema fuscum
Helicopsyche borealis
HERBIVORES
Polypedium spp.
Ephemera simulans
Corynoneura spp.
Geora sp.
PLANTS
Psychomyia flavida
Isonychia albomanicata
Meridion
Achnanthes
Cymbella
Antocha sp.
Psephenus herricki
Cyclotella
Navicula
Nitzschia
Optioservus sp.
Psilotreta indecisa
and 14 other genera in lesser amounts
Agapetus sp.
Steneimis beameri

Figure 6.2 Partial food web of small stream community (from Cummings et al. 1966)

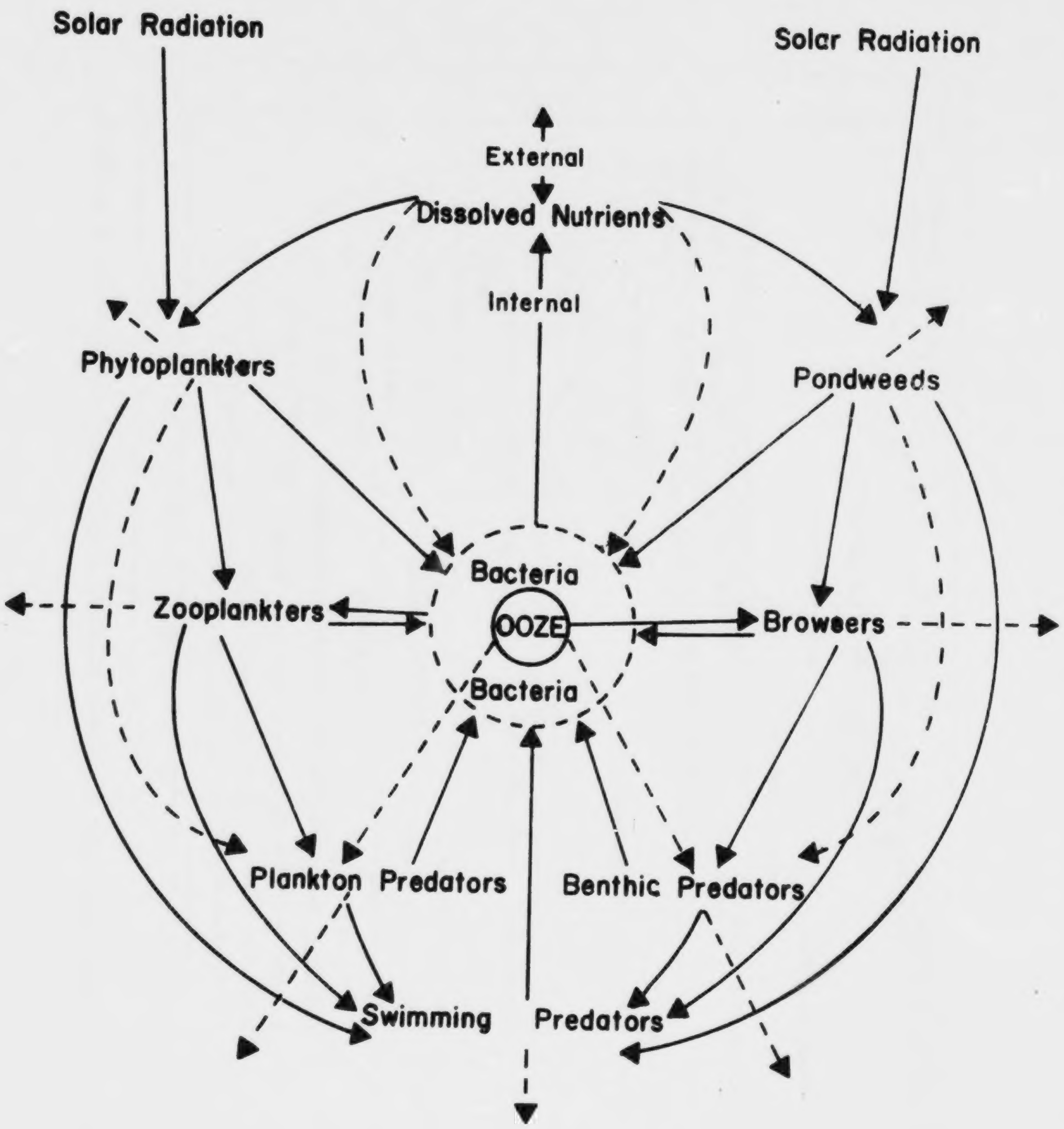
Solar Radiation
Solar Radiation
External
Dissolved Nutrients
Internal
Phytoplankters
Pondweeds
Bacteria
Zooplankters
OOZE
Browsers
Bacteria
Plankton Predators
Benthic Predators
Swimming Predators

Figure 6.4 Major pathways of material and energy transfer in a lake. (from Lindeman, 1941)

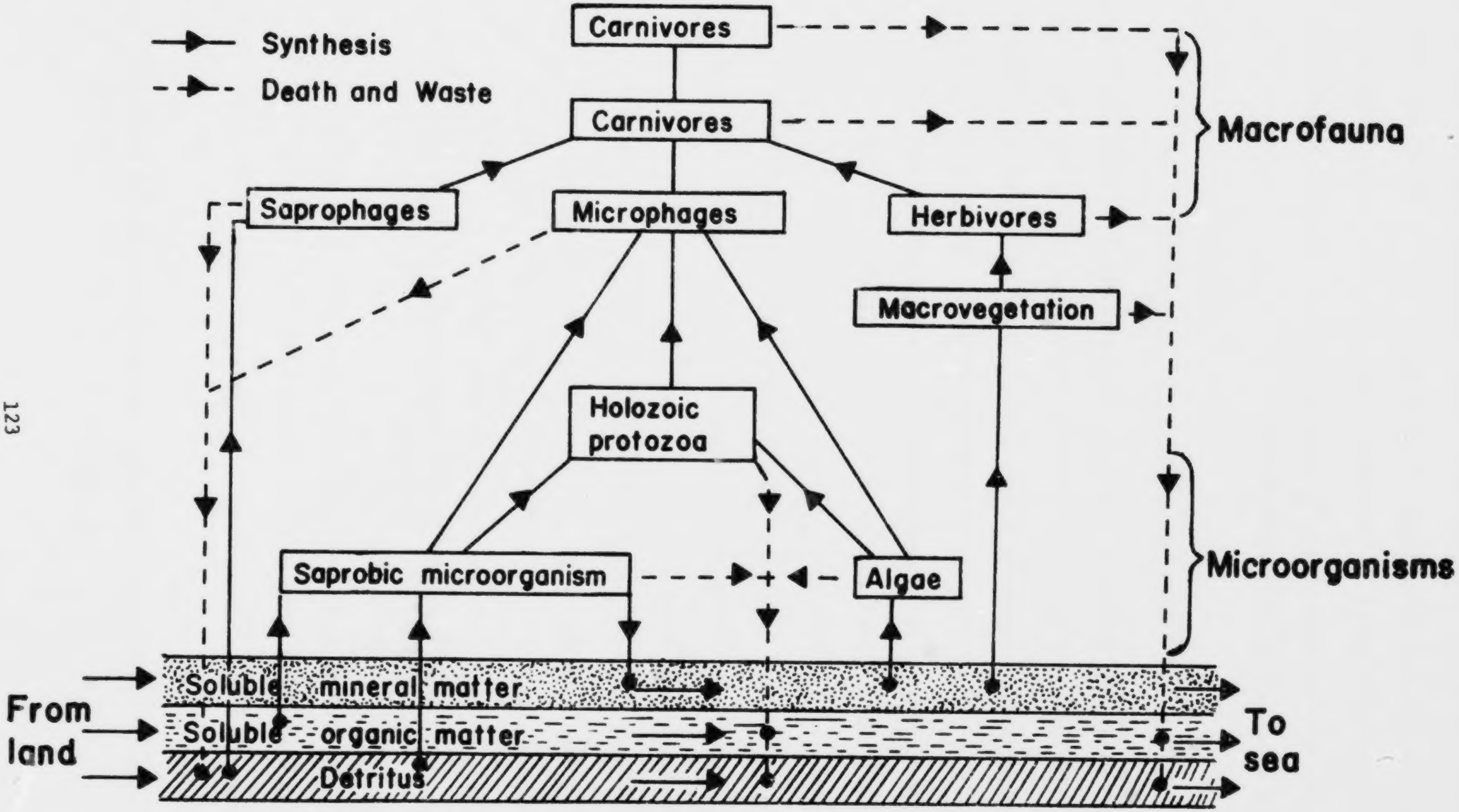
Synthesis
Death and Waste
Carnivores
Carnivores
Macrofauna
Saprophages
Microphages
Herbivores
Macrovegetation
Holozoic protozoa
Saprobic microorganism
Algae
Microorganisms
From land
Soluble mineral matter
Soluble organic matter
Detritus
To sea

Figure 6.3 Major pathways of material transport in stream community (from Hawkes, 1962)

by three different groups of investigators. These representations are simplified, but it remains clear that a disturbance at any point in such a system can produce alterations in many other parts of the system. When multiple alterations occur, the impact of the initial disturbance is very difficult to assess completely. This problem is discussed in the next section.

Problems of Assessing the Impact of Pollutants

Pesticides sometimes present a hazard to the environment. These chemicals, while contributing to man's health and welfare over the past 25 years, have sometimes been used without due consideration of their impact on nontarget organisms. Unanticipated effects have caused, and continue to cause, environmental problems. To avoid further environmental damage, it will be necessary to predict, over extended periods, the numerous effects of different types of pesticides (and other pollutants) in different environments.

The preceding discussion points out the complexity of most aquatic communities. Accurately prediction of the impact of pollutants on such a system requires increased knowledge of several basic aspects, including:

1) the residual level of pollutants maintained in the environment;
2) the magnitude and duration of periodic high concentrations of pollutants;
3) the species found in a community;
4) the effect of the residual and periodic high level(s) of pollutants on individual species;
5) the magnitude of any synergistic effects that occur when more than one pollutant is found in an environment; and
6) the effect on the community of altering the biology of an individual species.

It will also be necessary to know what changes take place in the community structure simply as a result of natural cycles. Some changes in community structure may occur that are independent of pesticides. Natural and induced changes must be differentiated before the impact of the pesticide can be properly assessed.

The difficulties associated with assessing the impact of pesticide pollution have been reviewed by a number of investigators, most recently by Cope (1971) and Pimentel (1971). The major concern is establishing causal relationships or differentiating between direct, indirect, and unrelated effects. Such relationships cannot be determined without the basic information indicated above. Very little basic information of this sort is currently available in the San Joaquin Valley, although efforts are under way to obtain more of it.

The environment must be monitored for residual pesticide levels as well as short-term pulses of high concentrations since some species are more susceptible to long-term low-level concentrations of a pesticide, while others are very susceptible to short-term pulses of high pesticide concentration. This information can be obtained only through an extensive monitoring system employed frequently enough to detect periodic high concentrations of pesticides. A recent report on pesticide monitoring by the California Water Resources Control Board (1971) indicates that monitoring programs in California have been "a fragmented and uncoordinated series of special studies of limited duration and scope." Only four such studies were reported for the San Joaquin Valley, all of short duration and limited to a small area. Should the recommendations of the Board's report be accepted, a monitoring program will be established that will provide some required information.

Table 6.2 lists some chemicals that we feel may have an impact on the aquatic environment. The top 100 chemicals from Table 2.1 (Chapter 2) are arranged by function (e.g., insecticides, herbicides) and chemical characteristics (e.g., organophosphorus, phenoxyacetic acids). Some chemicals from Table

Table 6.2 Some Chemicals Which May Have an Impact on Aquatic Environments in the San Joaquin Valley

Pesticide	Rank in San Joaquin Valley	Total Pounds Applied in San Joaquin Valley	Mammalian Toxicity Acute Oral LD_{50} - mg/kg^2
Insecticides			
Organochlorine (6)			
Toxaphene	7	1,768,162	90
DDT	9	874,114	113
Endosulfan	32	191,743	55-220
Chlordane	50	83,984	457-590
Methoxychlor	85	32,458	6,000
Perthane	94	22,729	8,170
Organophosphorus (20)			
Malathion	12	654,248	2,800
Parathion	13	621,046	13
Phorate	24	269,564	3.7
Guthion (Azinphos-methyl)	26	248,438	16.4
Methyl Parathion	29	188,980	208
Ethion	33	185,594	430
Naled	34	166,390	215
Baytex (Fenthion)	36	145,453	43
Delnav (Dioxathion)	38	127,274	630
Dylox (Trichlorphen)	41	118,484	250-265
Dimethoate	42	105,340	108
Diazinon	43	96,569	21
Azodrin	48	83,349	12.5
Disyston (Disulfoton)	51	55,443	28.3
Phosphamidon	67	53,987	1.12
TEPP	68	53,546	120
Phosalone	70	42,203	65
Meta Systox R (Oxydemeton-methyl)	75	34,348	5.0-6.8
Phosdrin (Mevinphos)	83	21,515	6.0-12
Systox (Demeton)	97		
Carbamates (2)			
Carbaryl (Sevin)	21	326,991	850
Methomyl	82	34,994	17-24
Inorganic (2)			
Lead Arsenate Standard	73	48,121	10-50
Lead Arsenate Basic	82	37,697	825
Acaricides (8)			
Dormant oils	6	2,039,574	Relatively harmless
Kelthane (organochlorine)	14	510,928	809
Omite	57	72,234	1,350-2,200
Carbophenothion (organophosphorus)	60	69,674	32.2
Tetradifon (organochlorine)	66	57,774	>5,000
Summer oils	71	51,974	Relatively harmless
Chlorobenzilate (organochlorine)	84	32,837	700-3,100
Aramite (organochlorine)	86	32,334	3,900
Herbicides (28)			
Phenoxyacetic Acids			
2,4-D group	20	336,132	375; acid 666-805; sodium salt 700; isopropyl ester 620; mixed butyl ester
MCPA	88	21,301	700
Triazines			
Simazine	45	102,258	>5,000
Amitrole	69	53,987	1,100-2,500
Atrazine	76	40,317	3,080
Dinitroanilines and Dinitrophenols			
Trifluralin	30	217,409	>10,000
Sinox (DNOC)	39	145,372	25-40
DNBP (Dinoseb)	52	83,100	50
Planavin	91	26,056	> 2,000
Arsenicals			
Ansar 170 (MSMA)	44	103,550	440
Ansar 138 (cacodylic acid)	54	77,618	1,350
Chlorinated Alkyl-Aryl Acids			
Dalapon	46	101,849	9,330
Sodium TCA	95	21,954	3,200-5,000
Bipyridyls			
Paraquat	53	79,633	155-203
Substituted Urea			
Diuron	64	59,458	3,400
Carbamates			
Tillam (Pebulate)	89	27,833	1,120[1]
Sutan	100	19,307	3,997-4,659
Inorganic			
Sodium chlorate	5	2,517,282	1,200
Oil of Vitriol (H_2SO_4)	22	324,381	Not available
Sodium arsenite	49	94,037	10-50
Magnesium chlorate	58	70,784	
Other			
Def-defoliant	27	242,821	325
Xylene	37	149,934	Not available
Propanil	55	75,834	1,384
Dacthal (Chlorothal-methyl)	59	70,038	>3,000
Diphenamid	78	37,381	1,050
Pyrazon	81	35,479	3,300
Bromacil	93	22,791	5,200
Fungicides (12)			
Dithiocarbamates			
Maneb	26	242,091	7,500
Nabam	90	27,308	395
Ziram	96	21,918	1,400
Heterocyclic nitrogen Dicarboximides			
Captan	40	131,254	9,000
Folcid (Captafol)	63	60,074	4,600
Inorganic			
Sulfur	3	9,138,557	Not available
Copper sulfa-pentahydrate	18	412,414	300
Zinc Sulfate	19	345,500	Not available
Copper Sulfate Basic	47	100,976	Not available
Copper oxychloride sulfate	61	66,960	Not available
Borax	65	58,238	2,660-5,140
Copper Hydroxide	87	32,087	Not available
Nematicides and Fumigants (6)			
Telone (Dichloropropene)	10	820,493	250-500
D-D mixture	11	755,751	140
Methyl bromide	17	441,887	Very toxic
Chloropicrin	25	251,624	Very toxic
DBCP	31	201,192	173
Ethylene dibromide	99	19,554	146

[1] Mammalian toxicity data from Pesticide Manual, British Crop Protection Council, 1966.

2.1 are excluded because they are not primarily pesticides (e.g., spreaders, urea, copper) or because seed weight is included (i.e., mercury-treated seeds), as explained in Chapter 2. Selection of these particular chemicals was necessarily arbitrary. Some types of pesticides (e.g., rodenticides, botanical insecticides) used in San Joaquin Valley were not present in the top 100, but these 100 chemicals include the major representatives of the most important groups of pesticides.

Table 6.2 is based on the quantity of pesticides applied, since numerous applications and large quantities indicate that a pesticide may have more impact. Although these chemicals are important now, patterns of use change. As some chemicals are displaced and others used more frequently, the pesticides having an impact on the environment may change considerably.

Some pesticides not listed in Table 6.2 may have an impact on a localized environment because of high application rates, such as chlorine, fenac, and dicryl. However, rates are comparably high for xylene, copper sulfate, and copper hydroxide, which are included in Table 6.2. Compounds which may present a local problem because of especially acute toxicity include compound 1080 (primarily a rodenticide) and endrin (an organochlorine insecticide).

Many chemically distinct types of pesticides are being used in the San Joaquin Valley. Previous environmental monitoring programs (reported in Pesticides Monitoring Journal, 1967-1971), have analyzed chlorinated hydrocarbon insecticides and phenoxyacetic acid herbicides almost exclusively. These two classes include only 10 of the 84 chemicals in Table 6.2. Clearly, an accurate description of pesticide pollution will require that monitoring programs in the Valley have a different emphasis from programs now in operation elsewhere.

If more than a few pollutants are present in any environment, extensive monitoring programs encounter logistic difficulties. Therefore, a monitoring program established in the Valley may be less extensive than desired. Metcalf et al. (1971) designed a microcosm that has been used extensively in assessing the environmental hazards from organophosphorus insecticides. If such a system were used to screen the major pesticides in the San Joaquin Valley, the initial monitoring program could emphasize the few pesticides most likely to produce deleterious effects.

The species in the study area must be enumerated before impact is assessed. Species differences in response to pesticides have been discussed for insects (Burke, 1959), algae (Fitzgerald, 1971), and fish (Hatch, 1957; Cope, 1971). The available data indicate that similar differences exist for other taxonomic groups. Hence, knowing the species present is essential to predicting the effects on particular habitat.

As mentioned, there have been very few studies of the aquatic biota within the San Joaquin Valley. The plankton of the San Joaquin River were studied by Allen (1920). More recent studies, by students at Fresno State College, have yielded insufficient information for developing extensive species lists of most taxonomic groups. Table 6.3 lists the fish species known to occur in Fresno County. We feel the list is representative, although some species found elsewhere in the valley may have been excluded. This is the only group of aquatic biota for which such a list can be developed at this time.

After the species present are known, the effect of a pesticide on individual species must be determined. Moore (1967) lists seven principal ways in which a pesticide can affect a species: direct toxic effect; secondary poisoning following pesticide accumulation in a food species; delayed expression of a toxic dose (e.g., a concentration that affects metamorphism in insects); removal of a food species; removal of a habitat species (e.g., aquatic weeds that provide protection for fish from predators); removal of competitors; and removal of predators. Some of these effects will occur if the pesticide concentration

Table 6.3 Fish Species of Fresno County (below 2,500 feet)[a]

Scientific Name		Common Name
Species	Genus	
Archoplithes	interruptus	Sacramento perch
*Carassius	auratus	Goldfish
Catostomus	occidentalis	Western sucker
Chaenobryttus	glulosus	Warmouth
Cottus	gulosus	Riffle sculpin
*Cyprinus	carpio	Carp
Entosphenus	tridentatus	Pacific lamprey
*Gambusia	affinis	Mosquito fish
*Gasterosteus	aculeatus	Three-spined stickleback
Hysterocarpus	traski	Tule perch
*Ictalurus	catus	White catfish
*Ictalurus	nebulosus	Brown bullhead
*Ictalurus	punctatus	Channel catfish
Lavinia	epilicauda	Hitch
*Lepomis	cyanellus	Green fish
*Lepomis	macrochirus	Bluegill
Micropterus	dolomieu	Smallmouth bass
*Micropterus	salmoides	Largemouth bass
Mylopharadon	conocephalus	Hardhead
*Notemigonus	crydeycas	Golden shiner
Orthodon	microlepidotus	Sacramento blackfish
Pagonichthys	macrolepidotus	Splittail
*Pimephales	promelas	Fathead minnow
Pomoxis	annularis	White crappie
*Pomoxis	nigromaculatus	Black crappie
Ptychocheilus	grandis	Sacramento squawfish
Roccus	saxatalis	Striped bass
*Salmo	gairdnerii	Rainbow trout
*Salmo	trotto	Brown trout

[a] This list of fish species was obtained from Mr. Robert Craig, Department of Zoology, U.C. Davis. It was compiled by searching the literature for records of occurrence and by consulting with individuals in the California Department of Fish and Game. It is the most comprehensive species list available for the study area of this report.

* Indicates species which have been used in evaluating pesticides, according to Lawrence (1968).

exceeds the acute toxicity of some species. However, the acute toxicity can vary with the sex, development stage, and nutritional state of the individuals involved (Cope, 1971). Toxicity is also affected by the fomulation of the pesticide (Alabaster, 1969) and with environmental conditions such as temperature, water hardness, pH, and dissolved oxygen. Toxicity will also depend on the duration of exposure. Jensen and Gaufin (1964 a,b) have shown that 2-day and 30-day LC_{50} (lethal concentration for 50% of a population) values frequently differ by more than an order of magnitude. This emphasizes the need to monitor chronic levels of pesticide pollution.

Since pesticide concentrations in the environment are frequently quite low, it is essential that sublethal effects also be studied. The physiology, behavior, and reproduction of fish and invertebrate species have been altered in the laboratory by exposure to low pesticide concentrations. Such changes are largely undetected in nature, although they may be having profound effects on the aquatic community.

One of the most complicated, and least studied, aspects of pesticide pollution involves interactions between pesticides when more than one is present in an environment. It is known that they can be antagonistic, additive, or synergistic, but studies to date have been limited to a few pesticides and species. O'Brien (1967) reviewed current knowledge of pesticide interactions. Cope (1971) indicated that only three studies have been conducted on synergistic or antagonistic effects on fish, and Moore (1967) pointed out that no work has been done on such effects on natural populations. Since numerous pesticides are applied to agricultural areas, there is a great need for extensive research on interactions between pesticides. The degradation products of various pesticides may also have synergistic effects.

Ivie and Casida (1970) discovered that rotenone catalyzes the photoisomerization of various cyclodienes. This finding might be used to lower residues of cyclodiene pesticides, which are quite toxic, but Georgacakis and Khan (1971) have found that the photoisomers of several of these compounds are more toxic to aquatic fauna than are the parent compounds. This investigation, one of the first concerned with the toxicity of degradation products to aquatic fauna, indicates the need for more research.

The problem of biomagnification is significant because it changes the effective concentrations of pesticides that a species encounters. The toxicity of pesticides to aquatic fauna is generally considered to result from exposure to some concentration of pesticide in the environment. If some species concentrate chemicals, predators of these species are exposed to abnormally high concentrations of pesticides. Furthermore, the predator contacts these pesticides as an oral dose rather than an environmental concentration. Macek (1969) provides a good review of current knowledge of biomagnification. Generally, the extent of magnification is thought to depend on the amount of pesticide present in various prey species as the pesticide moves up the food chain, but Hamelink et al. (1971) suggest that the concentration in any organism depends on exchange equilibria between the organism and its environment. Chadwick and Brocksen (1970) believe that more than one process is responsible for both the concentration and excretion of pesticides. These diverse points of view suggest the present confusion on this very important process.

The last major difficulty in assessing the impact of pesticides results from our rather primitive understanding of how ecosystems function. We can describe the operation of an ecosystem only in general terms. Consequently, a disturbance can be detected only when it has produced major alterations in the ecosystem. Even then it is difficult to assess the significance of the alterations (House et al., 1967). Most interactions of ecosystems are incredibly complicated and subtle, and changes in these relationships could easily go undetected. Understanding of these interactions will require much basic research by community ecologists, probably in conjunction with systems analysts. Such an understanding is nevertheless vital if we hope to assess the impact of any pollutants.

When one speaks of the impact of a pollutant on an ecosystem it is automatically assumed that the effects are deleterious, although this is not necessarily correct. Alterations due to pollutants should be evaluated in particular ecosystems as they affect the function of that ecosystem. However, most ecosystems have several functions that may be affected by a given pesticides. More importantly, the various uses of particular ecosystems may be poorly defined, so that it is difficult to assess whether a particular effect is deleterious or not. The most significant environmental alterations in the San Joaquin Valley have resulted from large-scale irrigated agriculture. Pesticide pollution, a small portion of this major alteration, should be assessed with respect to the over-all goals of the region.

Available Information on the Effects of Pesticides on Aquatic Environments

Despite the problems outlined in the previous section, one can attempt to assess the impact of pesticides. Our assessment is based on published literature, reports, and monographs. Procedures for searching the literature were discussed in the Foreword. More than 1,000 original articles were reviewed for this chapter. The information gathered so far represents one of the most extensive collections of information on pesticides and the aquatic environment in the country. It is hoped that this information can be computerized and retrieved as desired at a later date. For example, one should be able to recall all the literature on the effect on any species of a particular chemical. Similarly, one should be able to recall all literature on organophosphate insecticides and aquatic invertebrates. In short, this system should be flexible enough to accomodate both generic and specific searches. If such a service were maintained and made available for future projects it could save hours or days of searching, avoid unnecessary and costly duplication of the effort, and result in substantial saving of financial resources.

Literature Reviews: In recent years several reviews concerning pesticides have appeared in scientific and popular literature. The first extensive compilation of pesticide literature was provided by Rudd and Genelly (1956). They provide an excellent account of use patterns, important legislation, and public attitudes about the danger of pesticides to wildlife. They also gave a detailed account of the known effects on wildlife of 86 individual pesticides. Hazards to the environment from pesticides received public attention following the publication of "Silent Spring" (Carson, 1961). That book was followed by the much less emotional and better balanced "Pesticides and the Living Landscape" (Rudd, 1964). Rudd's book was reprinted, without major change, in 1970 and remains the best introduction to the environmental hazards that may result from pesticide pollution. Ecological problems resulting from pesticide use have been reviewed by Moore (1967). Symposia which merit special attention include those edited by Gould (1966), Moore (1966), Gillette (1969), and Miller and Berg (1969). A number of recent reviews discuss more specific subjects in greater depth. Lawrence (1962, 1969) compiled available data on herbicides and aquatic species, and House et al. (1967) reviewed the effects of repeated herbicide applications. Edwards (1970) discussed the problems associated with persistent pesticides, and Cope (1971) provided a recent evaluation of interactions between pesticides and wildlife. Excellent accounts of the effects of pesticides on specific groups of organisms have been presented by Johnson (1968) for fish, and Ware and Roan (1971) for plankton and microorganisms. These reviews were useful in acquiring a perspective from which to evaluate pesticide literature. A particularly useful reference has been "The Ecological Effects of Pesticides to Non-target Organisms" (Pimentel, 1971), an encyclopedic listing of the effects of insecticides, herbicides, and fungicides on many species, which was used to check the completeness of our literature search.

Available Data: The literature search as served two important functions, one qualitative and the other quantitative. The primary purpose was to obtain quantitative information on the effects of various concentrations of individual pesticides on important species in aquatic food webs. This information was to be correlated with the concentration of those chemicals found in the aquatic environments of the San Joaquin Valley. The data obtained were tabulated and are presented in appropriate sections throughout this chapter. All information obtained (except for fish) is presented, regardless of whether the species studied are known to be present in the valley, for two reasons: 1) in the absence of a comprehensive compilation of aquatic species in the valley it did not seem desirable to eliminate any species; and 2) most data are for only a few species, and making generalizations from these data is necessary.

Innumerable reports in both the popular press and scientific journals have decried the environmental destruction resulting from the indiscriminate use of pesticides. The standard rebuttal has been that care in using pesticides will avoid environmental hazards. Frequently, these presentations have been clearly biased; they either ignore what data are available or argue from very limited data. Much of the discussion in the literature we collected was clearly biased in one direction or the other, and has not been very helpful for assessing the impact of pesticide pollution in the aquatic environment.

Even so, considerable data have been accumulated. Tables 6.4-6.8 are compiled from literature we had access to. These tables are designed to indicate whether information is available on the effects of individual chemicals on

Table 6.4 Available Information on Effect of Organochlorine Insecticides and Acaricides to Aquatic Species

Species	Toxaphene	DDT	Kelthane	Endosulfan	Chlordane	Tetradifon	Chlorobenzilate	Methoxychlor and Aramite	Perthane
Primary producers									
Phytoplankton	x	x	-	x	-	x	-	x	-
Attached algae	x	x	-	-	-	-	-	-	-
Vascular plants									
-submerged	-	-	-	-	-	-	-	-	-
-emergent	-	-	-	-	-	-	-	-	-
-floating	-	-	-	-	-	-	-	-	-
Consumers									
Zooplankton									
-protozoa	x	x	-	-	-	-		-	-
-rotifers	x	-	-	-	-	-		-	-
-crustacea	x	x	x	x	-	x	x	x	x
Benthic invertebrates									
-annelids	x	x	x	x	-	x	-	-	x
-insects	x	x	x	x	-	x	-	x	-
-crustacea	x	x	-	x	-	x	-	x	-
-mollusca	x	-	-	-	-	-	-	-	-
Fish	x	x	x	x	x	x	x	x	x
Decomposers									
Fungi	-	x	-	-	-	-	-	-	-
Bacteria	-	x	-	-	-	-	-	-	-

(x) Some information (laboratory or field) was obtained by our literature search procedure.

(-) No information was obtained.

Table 6.5 Available Information on Effect of Organophosphorus Insecticides and Acaricides on Aquatic Species

Species	Parathion	Malathion	Phorate	Guthion	Methyl parathion	Ethion	Naled	Baytex	Delnav	Dylox	Dimethoate	Diazinon	Azodrin	Disyston	Carbopheno-thion	Phosphami-don	TEPP	Phosalone	Meta-Sys-tox-R	Phosdrin	Systox
Primary producers																					
Phytoplankton	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Attached algae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Moss	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vascular plants																					
-submerged	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-emergent	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-floating	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Consumers																					
Zooplankton																					
-protozoa	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-rotifers	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-crustacea	x	x	-	x	x	x	x	x	-	x	x	x	-	-	x	x	-	-	-	-	-
Benthic invertebrates																					
-annelids	x	x	-	x	x	x	-		-	x	-	x	-	-	-	-	x	-	x	-	x
-insects	x	x	-	x	-	x	x	x	-	x	x	x	-	x	-	x	-	-	x	x	-
-crustacea	x	x	x	x	x	x	x	x	x	x	x	x	-	x	x	x	x	-	x	x	-
-mollusca	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fish	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-
Decomposers																					
Fungi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteria	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(x) Some information (laboratory or field) was obtained by our search procedure.

(-) No information was obtained.

Table 6.6 Available Information on Effect of Other Insecticides and Acaricides on Aquatic Species

Species	Carbaryl	Methomyl	Lead arsenate	Dormant oils	Omite	Summer oils
Primary producers						
Phytoplankton	x	-	-	-	-	-
Attached algae	-	-	-	-	-	-
Vascular plants						
-submerged	-	-	-	-	-	-
-emergent	-	-	-	-	-	-
-floating	-	-	-	-	-	-
Consumers						
Zooplankton						
-protozoa	-	-	-	-	-	-
-rotifers	-	-	-	-	-	-
-crustacea	x	-	-	-	-	-
Benthic invertebrates						
-annelids	-	-	-	-	-	-
-insects	x	-	-	-	-	-
-crustacea	x	-	-	-	-	-
-mollusca	-	-	-	-	-	-
Fish	x	-	-	-	-	-
Decomposers						
Fungi	-	-	-	-	-	-
Bacteria	-	-	-	-	-	-

(x) Some information (laboratory or field) was obtained by our literature search procedure.

(-) No information was obtained.

Table 6.7 Available Information on the Effect of Herbicides on Nontarget Aquatic Species

Species	Sodium chlorate	2,4-D	Oil of Vitriol	Def-defoliant	Trifluralin	Xylene	Sinox	Ansar 170	Simazine	Dalapon	Sodium Arsenite	DNBP	Paraquat	Ansar 138	Propanil	Magnesium chlorate	Dacthal	Diuron	Amitrole	Atrazine	Diphenamid	Pyrazon	MCPA	Tillam	Planavin	Bromacil	Sodium TCA	Sutan
Primary producers																												
Phytoplankton	-	x	-	-	-	-	-	-	-	-	x	-	x	-	-	-	x	x	-	-	-	-	x	-	-	x	-	-
Attached algae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vascular plants																												
-submerged	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-emergent	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-floating	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Consumers																												
Zooplankton																												
-protozoa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-rotifers	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-crustacea	-	x	-	-	x	-	-	-	-	x	x	-	x	-	-	-	-	x	x	x	-	-	x	-	-	-	-	-
Benthic invertebrates																												
-annelids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-
-insects	-	x	-	x	x	-	x	-	x	x	x	x	x	x	-	-	-	x	-	x	-	-	-	-	-	-	-	-
-crustacea	-	x	-	x	x	-	-	-	x	x	x	-	x	-	-	-	-	x	-	x	-	-	-	-	-	-	-	-
-mollusca	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-
Fish	x	x	-	x	x	-	x	-	x	x	-	x	x	x	-	-	-	x	x	x	-	x	x	-	-	-	x	-
Decomposers																												
Fungi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteria	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(x) Some information (laboratory or field) was obtained by our search procedure.

(-) No information was obtained.

Table 6.8 Available Data on Effect of Miscellaneous Pesticides on Aquatic Species

Species	Sulfur	Copper sulfa pentahydrate	Zinc sulfate	Maneb	Captan	Copper sulfate	Copper oxychloride	Folcid	Borax	Copper hydroxide	Nabam	Ziram	Telone	D-D mixture	Methyl bromide	Chloropicrin	DBCP	Ethylene dibromide
	Fungicides												Nematicides and Fumigants					
Primary producers																		
Phytoplankton	-		-	x	x	x	-	-	-	-	x	-	-	-	-	-	-	-
Attached algae	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vascular plants																		
-submerged	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-emergent	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-floating	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Consumers																		
Zooplankton																		
-protozoa	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
-rotifers	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
-crustacea	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Benthic invertebrates																		
-annelids	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-insects	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
-crustacea	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-mollusca	-		-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-
Fish	-		-	-	-	x	x	-	-	-	x	x	-	-	-	-	-	-
Decomposers																		
Fungi	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteria	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(x) Some information (laboratory or field) was obtained by our literature search procedure.
(-) No information was obtained.

different components of the aquatic ecosystem, and to indicate where new studies are needed. The segments of our generalized aquatic ecosystem are listed by rows, and specific pesticides in columns. An *x* means that some information is available on the effect of that chemical on the biota concerned. A dash (-) means that no information is available. No attempt is made to evaluate these data. The compilations merely indicate whether information is available on the matters concerned. Pimentel (1971) has observed that the most-studied pesticides are not necessarily the most dangerous or even those used most widely. That observation is substantiated by our study. Thus, Telone and D-D mixture, used in large quantities (See Table 2.2 in Chapter 2), have seldom been studied. In contrast, Endrin is probably the second-most studied pesticide, although only 421 pounds (Table 2.2) were used in our study area in 1970. Nevertheless, these charts on availability of data may help in identifying the areas in greatest need of research.

The bulk of our information concerns the effects of insecticides or herbicides on a few invertebrate and fish species. Knowledge is limited on the effects of pesticides on primary producers and decomposers. There is very little work on the protozoans or rotifers, important groups of zooplankton, and surprisingly little on annelids and molluscs, groups that constitute the bulk of the benthic biomass in many environments. Each of the components of the biological community is important for the functioning of the community, and pesticide effects must be elucidated at these various levels of the food chain. Some groups of pesticides also have been poorly investigated. Knowledge on pesticide effects decreases in the following order: insecticides and acaricides   herbicides   fungicides   nematocides and fumigants. Increasing applications of these latter pesticides increase the need for additional studies on their effect on various aquatic biota. These are some of the many unexplored areas involving pesticide-biota interactions that need close attention.

The data that have been useful in our evaluation can be divided into laboratory and field observations. Laboratory experiments have usually determined the LC_{50} (TL_m) value of a pesticide for some species. LC_{50} is the concentration of pesticide in the environment which kills 50% of a species in a given period under the experimental conditions. It is important to note that the LC_{50} is the inverse of toxicity. That is, pesticides which are the most toxic have the lowest LC_{50} values. Studies have frequently described the LC_{50} of many different pesticides for one or a few species. Sometimes a pesticide was selected and its effect on several species was determined. Occasionally, a different value has been used, such as an EC_{50}. EC_{50} is the concentration which immobilizes 50% of a species in a given period. We have compiled LC_{50} values in tables according to type of pesticide and organism. Tables are provided on zooplankton, benthic invertebrates, and fish--for organochlorine insecticides, organophosphorus insecticides, and herbicides.

Laboratory investigations have recently been made on physiological mechanisms through which a pesticide acts (Cope, 1971). When the physiological responses to pesticides have been described, it will be easier to predict the effect of sublethal concentrations.

Laboratory experiments generally indicate the response of a single species to a given pesticide under constant conditions. Such observations are necessary, but direct extrapolation to field conditions is frequently impossible. Wilson and Bond (1970) have shown that the LC_{50} of benthic invertebrates can be increased by an order of magnitude by including sediment in the experimental container. Crosby and Tucker (1966) took the survivors of an immobilization experiment on Daphnia magna, placed them in fresh (pesticide-free) solution, and found that all those exposed to paraquat at 6 ppm died within two days even though they appeared healthy. These results indicate the caution needed in extrapolating from laboratory observations.

Field observations have frequently been made after pesticides were applied to an aquatic environment, either intentionally or accidentally. These observations may be more meaningful than laboratory determinations in assigning acceptable levels of pesticide concentration in waterways. However, since field observations are complicated by subtle interactions between species in nature, it is difficult to determine whether a given effect results directly or indirectly from pesticide application or perhaps from some completely extraneous factors. Pesticide pollution is claimed by some to be the major cause of fish kill, but the actual cause of death is usually undetermined. Even if pestidices are responsible they may act indirectly by making fish more susceptible to disease, depressing the oxygen content of the water, or in some other manner. There is a great need for increased field observations of accidental contamination as well as experimentation with known pesticide concentrations in the natural environment. Field observations on pesticides used in the San Joaquin Valley are listed in tables in this chapter (Table 6.14 for organochlorine insecticides, 6.18 for organophosphate insecticides, and 6.23 for herbicides).

We shall discuss the various types of available data as they relate to specific groups of pesticides.

Effects of Pesticides on Aquatic Environments

Pesticides can have direct or indirect effects on aquatic biota (Hunt and Keith, 1968). Direct effects are those resulting from the toxic action of pesticides during acute or chronic exposure. Indirect effects result from environmental changes brought about by the use of pesticides. Despite the numerous subtle effects possible in aquatic ecosystems, their frequency and magnitude have received little study, so their significance is diffisult to evaluate. Consequently, most assessments of ecological impact are based on direct toxic effects to fish species.

Fish-kill data are useful for locating geographic areas where major harm from pesticides is likely. However, an analysis based solely on fish-kill data certainly underestimates the magnitude of pesticide effects. The California Department of Fish and Game (1970) has compiled information on fish and wildlife losses caused by various pollutants for the years 1965 through 1969. Data on fish kills in the San Joaquin Valley are summarized in Tables 6.9 and 6.10. The data indicate that fish kills have been relatively few from pesticides compared with other causes. Also, loss of game fish has been less than the loss of non-game fish. The California Department of Fish and Game initiated a systematic approach to reporting and investigating fish kills in 1963. Fish kills from pesticides were greatest in 1963, declining steadily since then (Hunt and Linn 1970). The Estimate of environmental impact of pesticides in Table 6.9 and 6.10 is minimal for two reasons: Some losses may have been undetected or unreported; and some reported losses were not fully analyzed. Thus, some fish kill recorded as "unknown" may have been due to pesticides.

Besides fish kills, changes in fisheries have probably occurred that have not been properly documented. Hunt and Linn (1970) cite reports of fisheries that once flourished but are now absent, though no definitive information is available on this subject. Indirect effects of pesticides on wild fish populations have gone undetected in California, but Hunt and Linn (1970) conclude that "the probability that they can occur under present conditions dictates the need for further action."

According to Nicholson and Hill (1971), pollution problems that are severe over a large area result from the use of pesticides that are toxic, persistent, in widespread and voluminous use, and capable of being taken up and concentrated. Deleterious effects may result in a localized area if a pesticide satisfies any of these conditions. Localized effects are usually temporary, however, and may

Table 6.9 Number of Fish Kills from Pesticides and Other Pollutants[a] Reported for Counties of the San Joaquin Valley, 1965-1969[b]

County	Cause	1965	1966	1967	1968	1969
San Joaquin	Pesticides	1	5	1	0	3
	Other	1	3	3	5	8
Stanislaus	Pesticides	2	0	0	0	0
	Other	0	0	0	4	2
Merced	Pesticides	1	0	1	1	0
	Other	1	0	1	2	1
Madera	Pesticides	0	0	0	0	0
	Other	2	0	0	0	0
Fresno	Pesticides	0	0	1	2	0
	Other	1	1	0	2	1
Kings	Pesticides	0	0	0	4	0
	Other	0	0	0	1	1
Tulare	Pesticides	0	0	0	0	1
	Other	0	0	0	2	0
Kern	Pesticides	0	0	0	0	0
	Other	0	0	0	0	0

[a] Other includes fish kills from unknown cause.

[b] California Department of Fish and Game, 1970.

Table 6.10 Total Number of Fish Killed by Pesticides and Other Pollutants[a] Reported for Counties of the San Joaquin Valley, 1965–1969[b]

County	Cause	1965		1966		1967		1968		1969	
		Game Species	Non-game Species	Game Species	Non-game Species	Game Species	Non-game Species	Game Species	Non-game Species	Game Species	Non-game Species
San Joaquin	Pesticides	150	750	1,014	8,725	0	6,000	0	0	1,825	1,825
	Other	0	26,000	200	6,157	8,910	700	30,575	2,000	1,206	12,400
Stanislaus	Pesticides	27	775	0	0	0	0	0	0	0	0
	Other	0	0	0	0	0	0	32,800	525	15,027	40,075
Merced	Pesticides	0	1,325	0	0	2	1	1,025	0	0	0
	Other	0	1,025	0	0	110	1,000	200	1,506	325	250
Madera	Pesticides	0	0	0	0	0	0	0	0	0	0
	Other	350	75	0	0	0	0	0	0	0	0
Fresno	Pesticides	0	0	0	0	0	3	1,375	0	0	0
	Other	25	75	805	100,000	0	0	400	50	25	0
Kings	Pesticides	0	0	0	0	0	0	2,675	3,000	0	0
	Other	0	0	0	0	0	0	100	550	4,000	25
Tulare	Pesticides	0	0	0	0	0	0	0	0	(1,000 Total)	
	Other	0	0	0	0	0	0	350	1,000	0	0
Kern	Pesticides	0	0	0	0	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0	0	0	0

---

[a] Other includes fish killed from unknown cause.

[b] California Department of Fish and Game, 1970.

not be a cause of concern. Since different groups of pesticides differ with regard to the above criteria, danger to the San Joaquin Valley is assessed here for the pesticides applied there in the greatest quantity.

Insecticides and acaricides: Thirty-eight of the top 100 pesticides used in the San Joaquin Valley are applied primarily to control insects or mites (Table 6.2). This is understandable when one considers that the major economic losses from agricultural pests in fiscal 1968-1969 were from mites ($56,270,099), corn earworms ($38,192,365), and aphids ($29,806,631) (Hawthorne, 1970). Most (31) of the large number of insecticides and acaricides belong to two classes, organochlorine and organophosphorus. The few others are discussed individually.

Organochlorine compounds: The best-studied group of all pesticides is the organochlorine compounds, especially DDT. This is partly because they were the first organic pesticides to be synthesized and used in large quantities. However, major research efforts have been conducted because biomagnification and persistence are particularly characteristic of organochlorine compounds (Mitchell, 1966; Nicholson and Hill, 1971). Since they become concentrated in biological material, West (1966) believes there may be no safe concentration in water.

Much research on residue determinations in various species has been conducted and recently reviewed by Dustman and Stickel (1966), Stickel (1968), Edwards (1970), and Pimentel (1971). Figure 6.5 indicates typical concentrations of DDT found in various components of the ecosystem. Pesticide residues have been determined in California for fauna of Clear Lake (Hunt and Bischoff, 1960; Linn and Stanley, 1969) and the Tule Lake National Wildlife Refuge (Godsef and Johnson, 1968). Analyses of pesticide residues in the San Joaquin Valley are still insufficient to determine whether bioaccumulation poses a danger to aquatic fauna

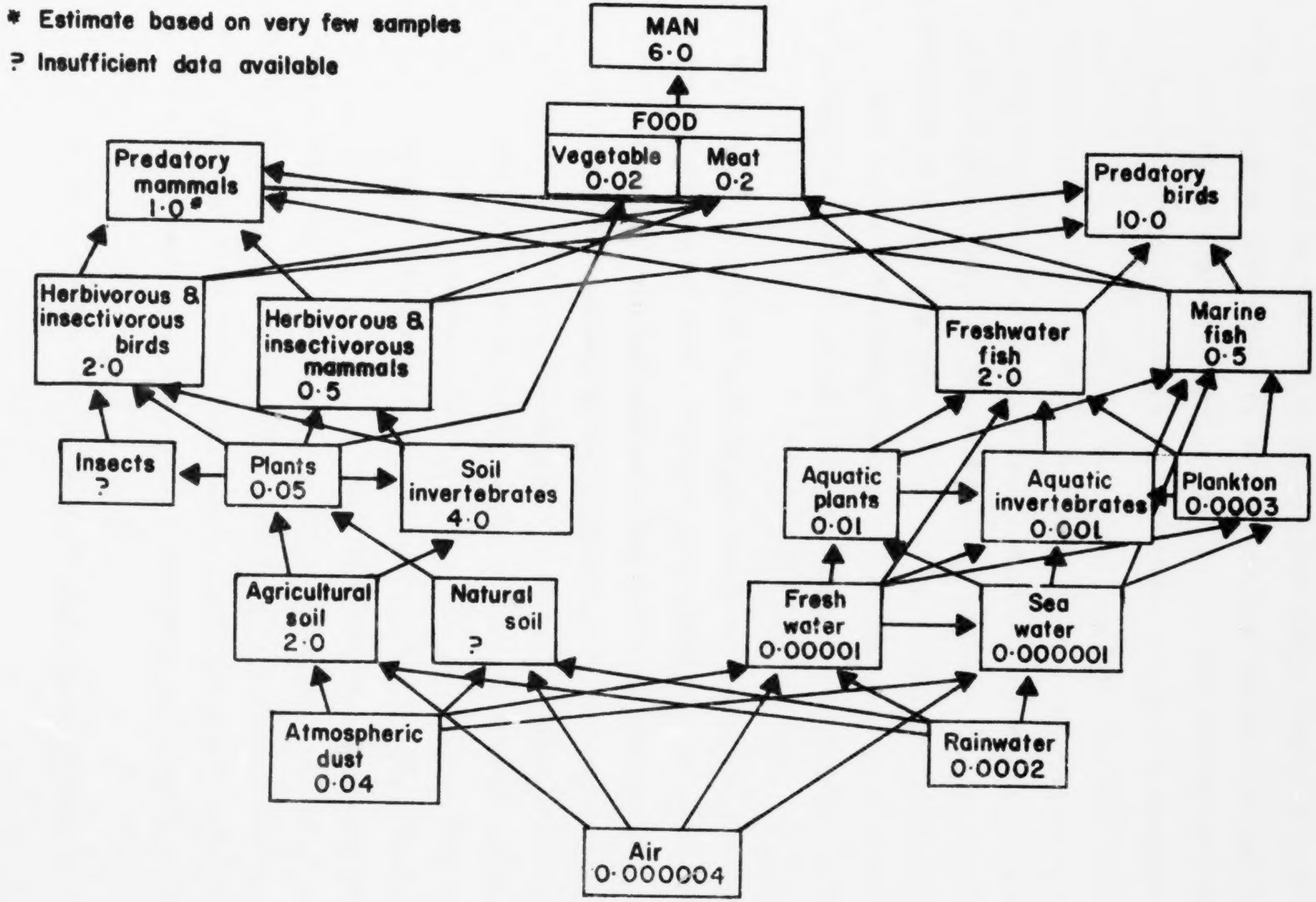
* Estimate based on very few samples
? Insufficient data available
MAN 6·0
FOOD
Vegetable 0·02
Meat 0·2
Predatory mammals 1·0*
Predatory birds 10·0
Herbivorous & insectivorous birds 2·0
Herbivorous & insectivorous mammals 0·5
Freshwater fish 2·0
Marine fish 0·5
Insects ?
Plants 0·05
Soil invertebrates 4·0
Aquatic plants 0·01
Aquatic invertebrates 0·001
Plankton 0·0003
Agricultural soil 2·0
Natural soil ?
Fresh water 0·00001
Sea water 0·000001
Atmospheric dust 0·04
Rainwater 0·0002
Air 0·000004

Figure 6.5 Typical amounts of DDT (ppm) in the environment. (from Edwards, 1970)

there (California Water Quality Control Board, 1971). Hunt and Linn (1970) suggest that the pesticide residues in striped bass may be high enough to interfere with reproduction, although that has not been documented. As with many other pesticide problems, the significance of residue levels has not yet been established (Wadleigh, 1968).

Organochlorine compounds have been the known or probable cause of numerous fish kills in the San Joaquin Valley (California Department of Fish and Game, 1970). The magnitude of this problem is decreasing, however, because of changing patterns of pesticide use (Table 2.6). The concentration of chlorinated hydrocarbons in the San Joaquin River decreased steadily from 1963 to 1968 (California Water Quality Control Board, 1971) and is expected to continue to decline.

Tables 6.11, 6.12, and 6.13 list LC_{50} values of organochlorine compounds to zooplankton, benthic invertebrates, and fish. These values are significantly higher than the concentrations of organochlorine compounds that have been found in the valley (Green _et al_., 1965; Bailey and Hannun, 1967; California Water Quality Control Board, 1971). Thus, direct toxicity to aquatic fauna from organochlorine applications is probably uncommon. Table 6.14 includes information on some environmental effects that have been observed following applications of organochlorine insecticides. The danger results not from acute toxicity but from biomagnification and persistence.

It is unlikely that organochlorine pesticides have had more effect on the aquatic fauna than any other group of pesticides in the San Joaquin Valley. They will continue to have some effect because they are persistent in the environment, though their impact should decrease because pesticide use patterns are changing.

Organophosphorus compounds: With the decreasing use of organochlorine

Table 6.11 EC_{50} (immobilization) Values (ppb) of Organochlorine Compounds to Zooplankton

Species	Temperature	Time (hours)	Toxaphene	DDT	Endosulfan	Chlordane	Methoxychlor	Perthane	Kelthane	Tetradifon	Chlorobenzilate	Aramite	Reference
Daphnia pulex	21C	48	20	0.4									Cope, 1966
	60F	48	15	0.36		29	0.78				870	160	Sanders and Cope, 1966
	60F	48	15	0.36			0.8						FWPCA, 1968
	-	48		1.48(LC_{50})									Priester, 1965
Daphnia magna	68F	24		4.4			3.7						Sanders and Cope, 1966
	68F	48			240			9.4	390			345	FWPCA, 1968
	68F	50		1.4			3.6						Sanders and Cope, 1966
	-	32		1									Anderson, 1945
	20C	50		1									Anderson, 1959
Daphnia carinata	78F	32		2.2									Matida and Kawasaki, 1958
Simocephalus serrulatus	60F	48				20	-				550		FWPCA, 1968
	60F	48	19	2.5		20	5				550	180	Sanders and Cope, 1966
	70F	48	10	2.8		24	5.6						Sanders and Cope, 1966

Table 6.12 LC$_{50}$ Values (ppb) of Organochlorine Compounds to Benthic Invertebrates

Species	Temperature	Time (hours)	Toxaphene	DDT	Endosulfan	Chlordane	Methoxychlor	Perthane	Kelthane	Tetradifon	Chlorobenzilate	Aramite	Reference
Stoneflies *Pteronarcys californica*	15.5C	24	18	41.	24	170	30						Sanders and Cope, 1968
	15.5	48	7.0	19	5.6	55	8.0						Sanders and Cope, 1968
	21C	48	7	16									Cope, 1966
	48-50F	48	7	19	5.6	55	8.		3				FWPCA, 1968
	11-12C	48		2,450									Jensen and Gaufin, 1964a
	11-12C	72		2,450									Jensen and Gaufin, 1964a
	11-12C	96		1,800									Jensen and Gaufin, 1964a; Gaufin, *et al.*, 1965
	15.5	96	2.3	7.0	2.3	15	1.4						Sanders and Cope, 1968
	12.8C	5 day		3,000									Jensen and Gaufin, 1964b
	12.8C	10 day		1,100									Jensen and Gaufin, 1964b
	12.8C	15 day		510									Jensen and Gaufin, 1964b
	12.8C	20 day		365									Jensen and Gaufin, 1964b
	12.8C	25 day		290									Jensen and Gaufin, 1964b
	12.8C	30 day		265									Jensen and Gaufin, 1964b
Acroneuria pacifica	11-12C	48		2,200									Jensen and Gaufin, 1964a
	11-12C	72		320									Jensen and Gaufin, 1964a
	11-12C	96		320									Jensen and Gaufin, 1964a; Gaufin *et al.*, 1965
	12.8C	5 day		2,150									Jensen and Gaufin, 1964b
	12.8C	10 day		440									Jensen and Gaufin, 1964b
	12.8C	15 day		240									Jensen and Gaufin, 1964b
	12.8C	20 day		84.0									Jensen and Gaufin, 1964b
	12.8C	25 day		76.0									Jensen and Gaufin, 1964b
	12.8C	30 day		72.0									Jensen and Gaufin, 1964b
Pteronarcella badia	15.5C	24	9.2	12.									Sanders and Cope, 1968
	15.5C	48	5.6	9.0									Sanders and Cope, 1968
	15.5C	96	3.0	9.0									Sanders and Cope, 1968
Claassenia sabulosa	15.5C	24	6.0	16.									Sanders and Cope, 1968
	15.5C	48	3.2	6.4									Sanders and Cope, 1968
	15.5C	96	1.3	3.5									Sanders and Cope, 1968
Caddisflies *Arctopsyche grandis*	51-54F	96		175									Gaufin *et al.*, 1965
Hydropsyche californica	51-54F	96		48									Gaufin *et al.*, 1965
Mayflies *Ephemerella grandis*	48-50F	96		25									Gaufin *et al.*, 1965
Baetis sp.	21C	48	47	12									
Amphipods *Gammarus lacustris*	70F	24	180	4.7	9.2	160	2.9		370		350		Sanders, 1969
	70F	48	70	2.1	6.4	80	1.3		140		100		Sanders, 1969
	60F	48	70	2.1	64	80	1.3	310	140		100		FWPCA, 1968
	70F	96	26	1.0	5.8	26	0.8		110		060		Sanders, 1969
	59F	96		9.									Gaufin *et al.*, 1965
Freshwater shrimp[a] *Palaemonetes kadiakensis*	21-27C	24	49.9	4.6		13.6							Navgi and Ferguson, 1970
	21-27C	24	229	6.8		334							Nagvi and Ferguson, 1970
Crayfish *Procambarus clarki*	16-32C	24		600									Muncy and Oliver, 1963
	16-32C	48		600									Muncy and Oliver, 1963
	16-32C	72		600									Muncy and Oliver, 1963

[a] Nagvi and Ferguson (1970) have determined LC$_{50}$ values for natural population of *Palaemonetes* included values for the most susceptible and most resistant populations.

Table 6.13 LC_{50} Values (ppb) of Organochlorine Compounds to Fish

Species	Temperature	Time (hours)	Toxaphene	DDT	Endosulfan	Chlordane	Methoxychlor	Perthane	Kelthane	Tetradifon	Chlorobenzilate	Aramite	References
Bluegill	12.7C	24	9.7		3.2	220	74						Macek et al. 1969
	18.3	24	6.8			170							Macek et al. 1969
	23.8C	24	6.6			95							Macek et al. 1969
	65F	48								1,100		35	FWPCA 1968
	25C	96	3.5	16		22	62						Henderson et al. 1959
		96	18	8									Macek and McAllister 1970[a]
Fathead minnow	25C	96	5.1	32		52	64						Henderson et al. 1959
		96	14	19									Macek and McAllister 1970[a]
Goldfish	25C	96	5.6	27		82	56						Henderson et al. 1959
		96	14	21									Macek and McAllister 1970[a]
Channel catfish		96	13	16									Macek and McAllister 1970[a]
Rainbow trout		24	50			50	52						Mayhew 1955
	55F	48	2.8		1.2	10	7.2	7	100		710		FWPCA 1968
	55F	48		5.2									Cope 1965
		96	11	7									Macek and McAllister 1970[a]
Brown trout		96	3	2									Macek and McAllister 1970[a]
Largemouth bass		96	2	2									Macek and McAllister 1970[a]
Carp		96	4	10									Macek and McAllister 1970[a]

[a] As reported by Pimental (1971).

Table 6.14 Some Reported Field Observations Following Application of Organochlorine Compounds

Chemical	Environment	Concentration	Effects	Location	Reference
Toxaphene	Reservoir	0.1 ppm	Chironimid larvae killed within three days, took 9 months to repopulate. *Chaoborus* larvae not killed immediately but absent 6 months later. Oligochaetes apparently unaffected.	Colorado	Cushing and Olive 1956
	Lake	0.05 ppm	Rapid loss from water column and uptake by biota. Some trout and bullheads killed, lake still toxic 9 months after treatment.	New Mexico	Kellman *et al*. 1962
	Lakes		Marked increase in growth rate of surviving yellow perch.	North Dakota	Warnick 1966
	Lakes	0.005-0.035 ppm	Fish toxicity varied but complete toxicity persisted for 7 months in some cases.	North Dakota	Hennegar 1966
		0.005-0.035 ppm	Dominant zooplankton (*Polyartha*, *Keratella*, *Asplancha*, *Bronchionus*, *Daphnia*, and *Cyclops*) apparently unaffected but numbers decrease at 0.09 ppm. Change in species composition in phytoplankton.	North Dakota	Needham 1966
	Lake	0.03-0.10 ppm	Used as fish toxicant, killed all game fish but not all trash fish. Not recommended as fish toxicant. Lake toxic to game fish for 10 months.	California	Johnson 1966
	Streams	1.5 ppm	Eliminated all sculpins and aquatic insects and caused reduction in other invertebrate groups. Benthic invertebrate populations had not recovered 1 year later.	Alaska	Meehan and Sheridan 1966
DDT[a]	River	1 lb/acre on watershed	Benthic stream invertebrates reduced in number immediately, biomass near normal after 1 year but change in species composition. No fish mortality but DDT residues found in fish 85 miles downstream and 2 years after application.	Wyoming	Cope 1961
	Streams	1/2 lb/acre	Drastic reduction in insect species, some of which did not return for two years. Salmon forced to feed on less desirable food species.	New Brunswick	Ide 1967
	Marsh		DDT accumulates rapidly in biota. After 2 years, low residues in plants, invertebrates and small vertebrates but high concentrations in larger vertebrates.	Ohio	Meeks 1967
	Streams		Accumulates in brook trout, suckers and crayfish. After 122 days concentration in fish, crayfish and bottom sediments had fallen to pre-treatment levels but watershed soils had high concentration.	Pennsylvania	Coll *et al*. 1967
	Streams	0.28 kg/ha.	Complete insect kill in 3 days, reappear after few weeks but complete repopulation takes more than 1 year. No direct fish mortality but high pesticide concentrations accumulate and growth rate falls because of lack of food.	Alaska	Reed 1967
Endosulfan			No reported observations.		
Chlordane			No reported observations.		
Methoxychlor	Streams	0.005 ppm	Applied as blackfly larvicide. Accumulates more slowly than DDT but produces comparable effects on aquatic fauna. Brook trout concentrate to 1.8 ppm in 7 days but some of this is lost when placed in freshwater.	New York	Burdick *et al*. 1968
Perthane			No reported observations.		
Kelthane			No reported observations.		
Tetradifon			No reported observations.		
Chlorobenzilate			No reported observations.		
Aramite			No reported observations.		

[a] There have been numerous recorded observations on DDT; we have included representative examples.

compounds there is a concomitant increase in organophosphorus compounds (Table 2.6). In terms of the top 100 chemicals (Table 6.2), crops in the San Joaquin Valley received more pounds of organophosphorus compounds than of organochlorine compounds. There have been very few detailed studies of environmental effects following the application of organophosphorus compounds. Thus, their impact cannot be adequately evaluated at present.

Tables 6.15, 6.16, and 6.17 list some EC_{50} and LC_{50} values of organophosphorus compounds for zooplankton, benthic invertebrates, and fish. As discussed in Chapter 5, persistence is much less for organophosphorus compounds than for organochlorine compounds, so the quantities entering the aquatic environment may be considerably lower. Since no monitoring programs have been established we cannot indicate how the actual concentration compares with the LC_{50} values. Another factor that lowers the hazard of organophosphorus compounds is the rate at which they are metabolized by aquatic fauna. Macek (1970) indicates that organophosphorus compounds generally turn over in less than a week. Thus, there is little chance for accumulation (biomagnification) within organisms in the food chain.

Some research has been conducted on the toxicity of organophosphorus degradation products. Wilson (1966), working with malathion, isolated 7 degradation products, all less toxic to fathead minnows than malathion. However, naled and dylox both hydrolyze to dichlorvos, which is more toxic to *Simocephalus serrulatus*, *Daphnia pulex*, and *Pteronarcys californica* than either parent product (Sanders and Cope, 1966; 1968). No general conclusions can yet be drawn about the significance of degradation products.

Table 6.18 lists environmental observations on the effect of organophosphorus compounds. The few observations made indicate that the primary danger is direct toxicity. Indirect effects will follow direct toxic effects, but their significance has not been evaluated.

Table 6.15 EC_{50} (immobilization) Values (ppb) of Organophosphorus Compounds to Zooplankton.

Species	Temperature	Time (hours)	Malathion	Parathion	Phorate	Guthion	Methyl parathion	Ethion	Naled	Baytex	Delnav	Dylox	Dimethoate	Diazinon	Axodrin	Disyston	Phosphamidon	TEPP	Phosalone	Meta-Systox R	Phosdrin	Systox	Carbophenothion	Reference
Daphnia pulex	21C	48	2			3								0.9										Cope, 1966
	-	48		0.76(LC_{50})																				Priester, 1965
	60F	48	1.8	0.6		3.2			0.35	0.8		0.18		0.9			8.8				0.16			Sanders and Cope, 1966
	60F	48	1.8			0.4			3.5	4.0				0.9							0.16			FWPCA, 1968
Daphnia magna	68F	24	0.9	0.8								0.12					12.5							Sanders and Cope, 1966
	68F	48				0.2	4.8	0.01				8.1	2500				4						0.009	FWPCA, 1968
	68F	50	0.9	0.8										4.3										Sanders and Cope, 1966
	20C	50	0.9	0.8										4.3										Anderson, 1959
	78F																							
Daphnia carinata	78F	32																						Matida and Kawasaki, 1958
	78F	64	0.2	0.5								0.25		0.8										Matida and Kawasaki, 1958
Simocephalus serrulatus	60F	48								3.1														FWPCA, 1968
	60F	48	3.5	0.37		4.2			1.1	0.92		0.70		1.8			12.0				0.43			Sanders and Cope, 1966
	70F	48	6.2	0.47		4.0			1.1	0.62		0.32		1.4			6.6				0.56			Sanders and Cope, 1966

Table 4.15. LC$_{50}$ Values (ppb) of Organophosphorus Compounds to Benthic Invertebrates.

Species	Temperature	Time (hours)	Malathion	Parathion	Phorate	Guthion	Methyl Parathion	Ethion	Naled	Baytex	Delnav	Dylox	Dimethoate	Diazinon	Azodrin	[illegible]	Phosphamidon	TEPP	Phosdrin	[illegible]	[illegible]	[illegible]	[illegible]	Reference
Stoneflies *Pteronarcys californica*	[illegible]	24	35	34		13		25	33	130		500	100	155		43	1,480			960	16			Sanders and Cope, 1968
	[illegible]	48	20	11		8		19	18	39		180	120	60 75		56	460			100	8.0			Sanders and Cope, 1968
	[illegible]	[illegible]	75			4																		Cope, 1966
	48-50F	24		11		4		14	16	100		40	110	60		10	460				4			FWPCA, 1968
	11-12C	48	240	7		[illegible]						40 49												Jensen and Gaufin, 1964a
	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]						69.0				10								Jensen and Gaufin, 1964a
	[illegible]	96	[illegible]	[illegible]		[illegible]										[illegible]								Jensen and Gaufin, 1964a; Gaufin *et al.*
	[illegible]	96	10	5.4		1.5		1.1	8.8	4.5		11	4	25		13	150			150	3			Sanders and Cope, 1968
	12.8C	5 day		16.0												[illegible]								Jensen and Gaufin, 1964b
	12.8C	10 day		[illegible]												[illegible]								Jensen and Gaufin, 1964b
	12.8C	15 day	45.0	[illegible]								61.0				[illegible]								Jensen and Gaufin, 1964b
	12.8C	20 day	24.0	[illegible]								33.0				[illegible]								Jensen and Gaufin, 1964b
	12.8C	25 day	15.5	[illegible]								11.0				[illegible]								Jensen and Gaufin, 1964b
	12.8C	30 day	8.4	[illegible]								8.9				1.4								Jensen and Gaufin, 1964b
Acroneuria pacifica	11-12C	48	17	6			31					[illegible]				[illegible]								Jensen and Gaufin, 1964a
	11-12C	72	16.0	2.9			11.0					77.0				11.0								Jensen and Gaufin, 1964a
	11-12C	96	7.0	2.8			8.1					79.0				8.1								Jensen and Gaufin, 1964a; Gaufin *et al.*, 1965
	12.8C	5 day	7.7	0.91												[illegible]								Jensen and Gaufin, 1965b
	12.8C	10 day	5.3	0.48												[illegible]								Jensen and Gaufin, 1965b
	12.8C	15 day	3.3	0.45								101.0				4.5								Jensen and Gaufin, 1965b
	12.8C	20 day	3.2	0.44								78.5				[illegible]								Jensen and Gaufin, 1965b
	12.8C	25 day	2.4	0.44								14.7				[illegible]								Jensen and Gaufin, 1965b
	12.8C	30 day	0.28	0.44								8.7				1.4								Jensen and Gaufin, 1965b
Pteronarcella badia	15.5C	24	10	8.0								[illegible]												Sanders and Cope, 1968
	15.5C	48	60	5.6								22												Sanders and Cope, 1968
	48-50F	24	4									23												FWPCA, 1968
	15.5C	96	1.1	4.2								11												Sanders and Cope, 1968
Claassenia sabulosa	15.5C	24	13	4.8								110												Sanders and Cope, 1968
	15.5C	48	4.0	1.5								70												Sanders and Cope, 1968
	15.5C	96	2.8	1.5								27												Sanders and Cope, 1968
Caddisflies *Arctopsyche grandis*	51-54F	96	32	7																				Gaufin *et al.*, 1965
Hydropsychl californica	51-54F	96	22.5	0.43																				Gaufin *et al.*, 1965
Mayflies *Ephemerella grandis*	48-50F	96	100	3		14						140				18								Gaufin, *et al.*, 1965
Baetis sp.	21C	48	6																					Cope, 1966
Amphipods *Gammarus lacustris*	70F	24	3.8	12	24	0.50		5.6	240	15	810	92	900	800	110	8.4	24		350	650		45		Sanders, 1969
	70F	48	1.8	6.0	14	0.25		3.2	180	17	690	60	400	500	[illegible]	3.8	52		200	110		19		Sanders, 1969
	60F	48	1.8	6		0.3		3.2	180	70	690	80	400	500	[illegible]	3.8	52			330		20		FWPCA, 1968
	70F	48	1.0	3.5	9.0	0.15		1.8	110	8.4	270	40	200	200	52	2.8	19		190	130		5.2		Sanders, 1969
	59F	96	[illegible]	12.8		0.12						50			240									Gaufin *et al.*, 1965
Freshwater shrimp[a] *Palaemonetes radiakensis*	21-23C	24		6.4		4.4	7.8																	Naqvi and Ferguson, 1970
	21-23C	24		11.9		16.8	23.3																	Naqvi and Ferguson, 1970
Crayfish *Procambarus clarki*	16-32C	24					50		6,000							20,000								Muncy and Oliver, 1963
	16-32C	48					40		4,000							6,000								Muncy and Oliver, 1963
	16-32C	72					40		4,000							5,500								Muncy and Oliver, 1963

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[a] Naqvi and Ferguson (1970) have determined LC$_{50}$ values for natural populations of *Palaemonetes kadiakensis*. We have included values for the most susceptible and most resistant populations.

Table 6.17 LC_{50} Values (ppb) of Organophosphorus Compounds to Fish

Species	Temperature	Time (hours)	Malathion	Parathion	Phorate	Guthion	Methyl Parathion	Ethion	Naled	Baytex	Delnav	Dylox	Dimethoate	Diazinon	Azodrin	Disyston	Phosphamidon	TEPP	Phosalone	Meta-systox R	Phosdrin	Systox	Carbophenothion	Reference
Bluegill	65F	24							220				28,000	52							41			Cope 1965
	12.7C	24	220			16																		Macek *et al.* 1969
	18.3C	24	140			16																		Macek *et al.* 1969
	23.9C	24	110			16																		Macek *et al.* 1969
	65F	48		47	5.5		8,000	230			14		9,600	30		40						81	225	Pickering *et al.* 1962
	25C	96	90	93		5.2	1,900				34	3,800				63		1,100				100		FWPCA 1968
		96	103			22	5,720			1,380														Macek and McAllister 1970[a]
Fathead minnow		96	8,650			235	8,900			2,404														Macek and McAllister 1970[a]
	25C	96	23,000	1,300		93	8,000				10,000	140,000				3,700		1,900				3,200		Pickering *et al.* 1962
	25C	96	12,500	700			7,500					51,000						790				3,600		Henderson and Pickering 1958
Goldfish		96	10,700			4,270	9,000			3,404														Macek and McAllister 1970[a]
	25C	96	450	2,700		1,300	9,600				32,000	99,000				6,500		21,000				11,000		Pickering *et al.* 1962
Channel catfish		96	8,970			3,290	5,710			1,680														Macek and McAllister 1970[a]
Rainbow trout													19,000											
	12.7C	24				25			240															Alabaster 1969
	65F	24	130			49	2,750							380							34			Macek *et al.* 1969
	55F	48				10						160			7		8,000				17			Cope 1965
		96	170			14				930														FWPCA 1968
	55F	96	68																					Macek and McAllister 1970[a]
Brown trout						4	4,740																	Cope 1965
Large mouth bass		96	285			5	5,220			1,340														Macek and McAllister 1970[a]
	25C	96	50	190							36													Pickering *et al.* 1962
Carp			6,390			695	7,130			1,160														Macek and McAllister 1970[a]
Striped bass												10,400												Wellborn 1969

[a] As reported by Pimentel (1971).

Table 6.18 Recorded Field Observations Following Application of Organophosphorus Compounds

Chemical	Environment	Concentration	Effects	Location	Reference
Malathion	Streams	2 lb/acre to watershed	No effect on fish species. Crayfish unaffected, other arthropod numbers decreased greatly but recovered quickly.	Ohio	Peterk and Giles 1964
	Aquarium	0.1 ppm	Altered the species composition of the algae but did not produce a persistent inhibitory effect on growth.		Christie 1969
Parathion	Ponds	0.4 lb/acre at biweekly intervals	No apparent effect on ducks living on ponds.	California	Keith and Mulla 1966
	Cranberry bogs	0.12 ppm	No apparent effect on mussels but kills 80% of fish. Both mussels and fish concentrate pesticide; fish metabolize 50% in less than a week. Parathion in water decreases to insignificant level in 144 hours.	Massachusetts	Miller *et al*. 1966
	Ponds	0.1 and 1.0 lb/acre	No apparent effects on caged mallard ducks or frogs but heavy mortality to mosquito fish (*Gambusia affinis*). Fish returned after 5-6 weeks. Free swimming mosquito fish contained up to 22 ppm parathion.	California	Mulla *et al*. 1966
	Pond	0.01-1.22 ppb	No apparent effects on fish, zooplankton, or oligochaeta populations. Reduction in insect numbers caused fish to feed on planktonic crustacea.	South Carolina	Nicholson *et al*. 1962, Grzenda *et al*. 1962
Phorate			No recorded observations.		
Guthion			No recorded observations.		
Methyl parathion	Lake	3 ppb	No apparent effects on benthic invertebrates or fish but significant depression in zooplankton levels.	California	Cook and Conners 1963
Ethion			No recorded observations.		
Naled			No recorded observations.		
Baytex	Pond	0.01 lb/acre	No apparent effect on brown bullheads or ducks	California	Burgoyne 1968
	Pond	11 ppb	No apparent effect on protozoa, microcrustaceae or fish but toxic to some benthic invertebrate species.	Florida	von Windeguth and Patterson 1968
	Pond	0.2 lbs/acre	No apparent effect on water chemistry or aquatic fauna except cladocerans. Cladoceran populations depressed for more than 3 months.	Florida	Patterson and von Windeguth 1964a
	Pond	0.24-0.27 lbs/acre	Provides effective control of midge populations, causes a reduction in immature Odonata populations.	Florida	Patterson and von Windeguth 1964b
	Rice fields	0.1 lb/acre	Did not appear to be hazardous to fish life.	California	Linn 1968
	Ponds	50 ppb	Changes composition of zooplankton in pond	Kansas	Ray and Stevens 1970
Delnav			No recorded observations.		
Dylox			No recorded observations.		
Dimethoate			No recorded observations.		
Diazinon	Cranberry bogs	0.32 ppm	Fish killed immediately after application. Both freshwater mussels and fish concentrate the pesticide from water. Pesticide disappears in 144 hours.	Massachusetts	Miller *et al*. 1966
Azodrin			No recorded observations.		
Disyston			No recorded observations.		
Phosphamidon	Streams	1 lb/acre to watershed	No apparent effect on Atlantic salmon or brook trout.	New Brunswick	Kerswill and Edwards 1967
	Streams		Tolerated by salmonid fish at doses higher than those normally required to control insects.	British Columbia	Schouwenburg and Jackson 1967
	Streams	1/2-1 lb/acre	No decline in number of orders or individuals of benthic fauna.	New Brunswick	Grant 1967
TEPP			No recorded observations.		
Phosalone			No recorded observations.		
Meta-systox R			No recorded observations.		
Phosdrin			No recorded observations.		
Systox			No recorded observations.		
Carbophenothion			No recorded observations.		

There have been no reports that organophosphorus insecticides have had significant effects on the aquatic environment in the San Joaquin Valley. Since they are generally quite toxic, their misuse could have profound effects. Generally they have been considered to be nonpersistent and to be metabolized readily by plants and animals. Recent work by Kilgore and Marei (in press), however, shows that parathion is translocated and stored in certain plants and that it persists for much longer periods of time than has been generally assumed. The possible implications for the aquatic environment are significant, and we believe that a monitoring program for organophosphorus compounds should be established as soon as possible with special attention given to the most toxic and persistent pesticides.

Other insecticides: Seven insecticides in Table 6.2 cannot be classified as organochlorine or organophosphorus compounds. Table 6.6 indicates that no data are available for these compounds, except for carbaryl. The LC_{50} values for carbaryl are listed in Table 6.19. Carbaryl is not persistent in the environment which reduces environmental hazard associated with its use. The other six pesticides, except for dormant oils, are applied in relatively low quantities and should not produce a major problem. Dormant oils are applied in large quantities but are primarily hydrocarbons, which can be metabolized by microorganisms. Large quantities should not reach the aquatic environment, and will act primarily as nutrients for microorganisms if they do.

A potential danger from the lead arsenate compounds is discussed under heavy metals.

Herbicides: Herbicides are increasing in use more rapidly than any other group of pesticide in the United States. The Weed Science Society of America lists over 120 organic herbicides, which account for more than 50% of all sales of pesticides (Foy and Bingham, 1969). The effects of herbicides to the aquatic

Table 6.19 LC_{50} Values (ppm) of Carbaryl to Aquatic Fauna

Species	Temp.	Time (hrs.)	LC_{50}	Reference
Zooplankton				
Daphnia pulex	60 F	48	0.0064	Sanders and Cope, 1966
	60 F	48	0.0064	FWPCA, 1968
Simocephalus serrulatus	60 F	48	0.0076	Sanders and Cope, 1966
Benthic Invertebrates				
Stone flies				
Pteronarcys californica	15.5 C	24	0.030	Sanders and Cope, 1968
		48	0.015	Cope, 1966
		48	0.013	Sanders and Cope, 1968
		96	0.0048	Sanders and Cope, 1968
Pteronarcella badia	15.5 C	24	0.0050	Sanders and Cope, 1968
		48	0.0036	Sanders and Cope, 1968
		96	0.0017	Sanders and Cope, 1968
Claassenia sabulosa	15.5 C	24	0.012	Sanders and Cope, 1968
		48	0.0068	Sanders and Cope, 1968
		96	0.0056	Sanders and Cope, 1968
Amphi pod				
Gammarus lacustris	70 F	24	0.040	Sanders, 1969
		48	0.022	Sanders, 1969; FWPCA, 1968
		96	0.016	Sanders, 1969
Cray fish				
Procambarys clarkii	16-32 C	24	5.0	Muncy and Oliver, 1963
		48	3.0	Muncy and Oliver, 1963
		72	2.0	Muncy and Oliver, 1963
Fish				
Three-spined stickleback		24	6.7	Stewart *et al.*, 1967
Brown trout	55 F	48	1.5	FWPCA, 1968
		96	1.95	Macek and McAllister, 1970
Rainbow trout		96	4.38	Macek and McAllister, 1970
Carp		96	5.28	Macek and McAllister, 1970
Largemouth bass		96	6.4	Macek and McAllister, 1970
Bluegill		96	6.76	Macek and McAllister, 1970
Redear sunfish		96	11.2	Macek and McAllister, 1970
Fathead minnow		96	14.6	Macek and McAllister, 1970
		96	13.0	Stewart *et al.*, 1967
Goldfish		96	13.2	Macek and McAllister, 1970
Channel catfish		96	15.8	Macek and McAllister, 1970
Black bullhead		96	20.0	Macek and McAllister, 1970

Table 6.20 EC_{50} (immobilization) Values (ppm) of Herbicides to Zooplankton.

Species	Temperature	Time (hours)	Sodium Chlorate	2,4-D acid	2,4-D [BEE]	2,4-D [PGBE]	2,4-D [dimethyl amine salt]	Oil of vitriol	Def defoliant	Trifluralin	Xylene	Sinox	Ansar 170	Simazine	Dalapon	Socium arsenite	DNBP	Paraquat	Ansar 138	Propanil	Magnesium chlorate	Dacthal	Diuron	Amitrole	Atrazine	Diphenamid	Pyrazon	MCPA	Tillan	Planavin	Bromacil	Sodium TCA	Sutan	Reference
Daphnia magna	21.1C	26		>100												6.5		11		4.8			47	23				100						Crosby and Tucker 1966
	21C	48		>100	5.6	0.1	4			0.56				1										30		56								Sanders 1970
	68F	48													6										3.6									FWPCA 1968
Daphnia pulex	60F	48								0.24					11	1.8		3.7					1.4											Sanders and Cope 1966
	60F	48								0.24								3.7					1.4											FWPCA 1968
Simocephalus serrulatus	60F	48								0.45					16	1.4		4					2											Sanders and Cope 1966
	60F	48														1.4																		FWPCA 1968

Table 6.21 LC$_{50}$ Value (ppm) of Herbicides to Benthic Invertebrates.

Species	Temperature	Time (hours)	Sodium chlorate	2,4-D acid	2,4-D [BEE]	2,4-D [PGBE]	2,4-D [dimethyl amine salt]	Oil of vitriol	Def defoliant	Trifluralin	Xylene	Sinox	Ansar 170	Simazine	Dalapon	Sodium arsenite	DNBP	Paraquat	Ansar 138	Propanil	Magnesium chlorate	Dacthal	Diuron	Amitrole	Atrazine	Diphenamid	Pyrazon	MCPA	Tillam	Planavin	Bromacil	Sodium TCA	Sutan	Reference
Amphipods																																		
Gammarus lacustris	70F	24			1.4	2.1	>100		0.36	8.8		8.8		30				38					0.7											Sanders 1969
	60F	48			0.76	1.8			0.23	5.6				21	>100			18					0.38											FWPCA 1968
	70F	48			0.76	1.8	>100		0.23	5.6				21				18					0.38											Sanders 1969
	70F	96			0.44	1.6	>100		0.10	2.2				13				11					0.16											Sanders 1969
G. fasciatus	15.5C	24			6.5	4.1	>100			3.2				>100						54			2.5										25	Sanders 1970
	15.5C	48		3.2	5.9	2.6	>100			1.8				>100						34			1.8	>100		>100							13	Sanders 1970
	15.5C	96			5.9	2.5	>100			1.0				>100						18			0.7										10	Sanders 1970
Isopods																																		
Asellus brevicaudus	15.5C	48			3.2	2.2	>100			2.0				100										>100		>100								Sanders 1970
Ostracods																																		
Cypridopsis vidua	21C	48			1.8	0.32	>8.0			0.25				3.2										32		50								Sanders 1970
Decapods																																		
Paleomonotes kadiakensis																								>100		58								Sanders 1970
Orconectes nais	15.5C	48			>100	>100	>100			50				>100										>100		>100								Sanders 1970
Stoneflies																																		
Pteronarcys californica	15.5C	24		56	11				3.8	13					>100	140		>100					3.6											Sanders and Cope 1968
	60F	48				1.8			2.3	4.2				50									2.8											FWPCA 1968
	21C	48				1.8				4.2						80																		Cope 1966
	15.5C	48		44	5.0				2.8	4.2					>100	120		>100					2.8											Sanders and Cope 1968
	15.5C	96		15	2.3				2.1	3.0					>100	38		>100					1.2											Sanders and Cope 1968

Table 6.22 LC_{50} Values (ppm) of Herbicides to Fish.

Species	Temperature	Time (hours)	Sodium chlorate	2,4-D acid	2,4-D [BEE]	2,4-D [PGBE]	2,4-D [dimethyl amine salt]	Oil of vitriol	Def defoliant	Trifluralin	Xylene	Simox	Amsar 170	Simazine	Dalapon	Sodium arsenite	DMBP	Paraquat	Ansar 138	Propanil	Magnesium chlorate	Dacthal	Diuron	Amitrole	Atrazine	Diphenamid	Pyrazon	MCPA	Planavin	Bromacil	Sodium TCA	Sutan	Reference
Bluegill		24																400										164					Davis and Hughes 1963
		24		8.0	2.1	2.1	542																										Hughes and Davis 1962
		24																															Hughes and Davis 1963
	85F	24								0.01				130	115								12										Cope 1965
	45F	24								1.30						58																	Cope 1965
		24													480																		Surber and Pickering 1962
	65F	48			2.1				36																								FWPCA 1968
		48			3.7									118	115								7.4										Bohmont 1967
		48		8.0	2.1	2.1	458																										Hughes and Davis 1963
	24C	48				0.9				0.019						44							7.4										Cope 1965
	85F	96								0.008																							Cope 1965
	45F	96								0.28																							Cope 1965
Rainbow trout	18C	24					250							95	300																		Alabaster 1969
	45F	24								0.21				68		100																	Cope 1965
	55F	48				0.96				0.011		0.21		5		36.5																	FWPCA
		48				1.1								56									4.3		12.6								Bohmont 1967
Fathead minnow		24													440																		Surber and Pickering 1962
Stripped bass		24																0.6															Wellborn 1969
		96																					3.1										Wellborn 1969
Largemouth bass		48																					4.2										Bond *et al.* 1959
Channel catfish		24	3,157																													2,000	Clemens and Sneed 1959

Table 6.21 Some Reported Field Observations Following Application of Herbicides

Chemical	Environment	Concentration	Effects	Location	Reference
Sodium chlorate			No recorded observations		
2,4-D^a	ponds		Non-toxic to benthic or planktonic fauna; biomass increased 5-6 times initial level.	U.S.S.R.	Braginskii 1962
	ponds		Increase in planktonic cyclopods, but toxic to *Bosmina longirostris* at 1 mg/l. At recommended dosages, acts as fertilizer.	U.S.S.R.	Brakins'kyyi and Rotova's'ka, 1960
	ponds	20-40 lb/acre	No significant change in number or weight of benthos	Michigan	Hooper 1958
	ponds		Increased microorganism counts (probably due to decaying vegetation) for 23-25 days.	U.S.S.R.	Petrak 1964
	ponds	10 ppm	19% of bluegills die in 8 days; increased growth in survivors.	Oregon	Cope, *et al.* 1970
	ponds	1-4 ppm	50% fewer mayflies, midges, caddisfly larvae, beetles and annelids.	Wisconsin	Walker 1962
	ponds	1 ppb	No significant change in Hexagenia population.	Wisconsin	Smith and Isom 1967
2,4-D and 2,4,5-T	forest	1 lb/acre	Streams do not have measurable concentrations.	Oregon	Norris 1968
Oil of Vitriol			No recorded observations		
Def Defoliant			No recorded observations		
Trifluralin			No recorded observations		
Xylene	creek		1500 fish killed	California	California Fish and Game 1970
Ansar 170			No recorded observations		
Simazine			At concentrations that control aquatic weeds, there is no apparent effect on benthic or planktonic fauna	U.S.S.R.	Braginskii 1962
	ponds	1-2 ppm	Not toxic to fish or other fauna in field but depressed dissolved oxygen concentration for several weeks.	Ontario	Schenk and Jarolimek 1966
	ponds	0.5 ppm	Populations of mayflies, mosquitos, biting midges, damselfly nymphs, aquatic beetles, worms, leeches and snails all reduced by 50% or more.	Missouri	Walker 1964
	ponds	25 ppm	About 50% of midges and worms killed.	Missouri	Walker 1964
Dalapon			No recorded observations.		
Sodium arsenite	ponds	4 ppm (manufacturer's recommendation)	No apparent effect on phytoplankton or ostracods, but drastically reduces copepods, cladocerans and rotifers.	New York	Cowell 1965
	ponds	4 ppm	Drastically reduces copepods, cladocerans and rotifers populations which take more than 90 days to recover.		Lawrence 1958
	ponds		Repeated applications may lead to concentration since phytoplankton accumulates to 714 ppm.		Dupree 1960
	ponds	8 ppm	Toxic to filamentous algae and many invertebrates. Inadvisable to use in fish ponds because of disruption of trophic system.	Michigan	Ball and Hooper 1963
	ponds	4 ppm	Benthic and planktonic populations reduced. Bluegill growth and survival depressed.	Wisconsin	Gilderhus 1966
Tokar			No recorded observations.		
Paraquat	ponds	1 ppm	Not toxic to sunfish, rainbow trout or catfish.		House *et al.* 1967
Ansar 138	ponds	2 lb/acre	Reduced algal productivity.	Florida	Oliver *et al.* 1966
Propanil			No recorded observations.		
Magnesium chlorate			No recorded observations.		
Dacthal			No recorded observations.		
Diuron	ponds	.5-3 ppm	Dissolved oxygen concentration reduced for several days. Toxic to some midges, mayflies and dragonflies.		McCraren *et al.* 1969
Amitrole	canals	4.5 kg/ha	Maximum concentration in water (98 ppb) reduced to less than 1 ppb in 2 hours.	Colorado	Demint *et al.* 1970
	pond	1 ppm	Persisted in water for more than 20 days.		Grzenda *et al.* 1966
Atrazine	pond	0.5-2.0 ppm	Populations of mayflies, midges, mosquitoes, caddisflies, annelids, snails and leeches reduced by at least 50% while damselfly and water beetle populations doubled.	Missouri	Walker 1964
Diphenamid			No recorded observations.		
Pyrazon			No recorded observations.		
MCPA			No recorded observations.		
Fillex			No recorded observations.		
Planavin			No recorded observations.		
Bromacil			No recorded observations.		
Sodium TCA	canal bank	3.8-5.9 lb/acre	Concentrations in water (31-138 ppb) are not hazardous to aquatic fauna.	Colorado	Frank *et al.* 1970
Solan			No recorded observations.		

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environment require special concern because the overwhelming proportion of pesticides applied directly to and around waterways are herbicides (Table 4.3). Table 6.2 indicates that the major herbicides used in the San Joaquin Valley belong to several different chemical classes. These various classes affect target and nontarget species in different manners (Weed Science Society of America, 1970). More than four million pounds of herbicides were applied in the San Joaquin Valley in 1970. Such large applications could present an environmental hazard, though little harm to the environment from misuse of herbicides has yet been reported. One reason that reported losses of wildlife are few is that a permit must be obtained from the Fish and Game Department before substances are applied directly to water (Hunt and Linn, 1970). Such a permit can be refused if there is danger of wildlife loss.

LC_{50} values of herbicides to aquatic fauna are listed in Tables 6.20 to 6.22. These values are generally higher than the LC_{50} values for insecticides, and considerably higher than the values usually encountered in the aquatic environment. Neururer and Slanina (1960) have suggested that only simazine approaches toxic concentrations in waterways. No toxicity data are available for several of the herbicides listed in Table 6.2, including Ansar 170, an arsenical compound.

Field observations made on herbicides are listed in Table 6.23. The following general statements can be made. Herbicides applied to running water do not seem to be a hazard. In standing water, the concentrations necessary to control aquatic plants are not toxic to the fauna. Only with sodium arsenite is there severe toxicity from applications of the manufacturer's recommended dose. The significance of alterations in the structure of the community is difficult to assess.

Damage to the environment from herbicides usually results indirectly from environmental alterations. Two major alterations affect the fauna. Since submerged vegetation frequently provides protection for fish species, its elimination makes them more susceptible to predation. Also, Walker (1964) mentions that eliminating this vegetation might alter the feeding habits of some species. A more general effect is a depression of dissolved oxygen concentration as a result of the decomposition of vegetable matter killed by herbicides.

It has been suggested that herbicides could accumulate in the environment and reach levels toxic to phytoplankton (Butler, 1965), _Daphnia_ _magna_ (Crosby and Tucker, 1966), or fish (Hilitbran, 1967). However, all of these investigations were conducted at concentrations seldom observed in nature.

The ecological impact of herbicides has been reviewed extensively by House _et_ _al_. (1967), and Mullison (1970 a,b) discussed the effects of herbicides on nontarget organisms and on the aquatic environment. Recent reviews on pesticide-wildlife interactions (Johnson, 1968; Cope 1971; Pimentel, 1971) have also briefly discussed the effects of herbicides on aquatic fauna. Except in the arsenite, studies just mentioned, all of those reports conclude that damage to the aquatic environment is unlikely from herbicides used as directed.

Miscellaneous pesticides: In addition to insecticides, millions of pounds fungicides, nematocides, and rodenticides are applied annually in the San Joaquin Valley. Several of these are also applied to the soil in high concentrations as fumigants. Even less information is available for assessing the impact of these types of pesticides than for insecticides and herbicides. Knowledge on fungicides, nematicides, and rodenticides in the aquatic environment is comparable to knowledge on insecticides approximately fifteen years ago, which, according to Cope (1971), was limited to "the benefits from pesticides as tools in management ... and acute toxicity of economic poisons to a few species."

Table 6.2 lists the pesticides that we consider to be most important in the San Joaquin Valley. Of these, 18 are not used primarily as insecticides or herbicides. Although over 13,000,000 pounds of these chemicals were applied in the San Joaquin Valley in 1970, none are mentioned in the "Handbook of Toxicity of Pesticides to Wildlife" (Tucker and Crabtree, 1970). "Ecological Effects of Pesticides on Non-Target Species" (Pimentel, 1971) includes information on DBCP and captan, but the effects of these two on aquatic species have apparently not been investigated. The literature search for this report yielded no additional information. Hence, it is unlikely that their overall environmental impact can be assessed with confidence for several years.

Some research has been conducted on the effects on aquatic species of the following fungicides: nabam, copper sulfate, copper oxychloride, sulfur, and lime sulfur. Significant quantities of these chemicals are being applied in the San Joaquin Valley. Of these, sulfur, which is ranked third in terms of pounds used in the San Joaquin Valley, and lime sulfur are not expected to have much impact on the aquatic environment. Sanders and Cope (1966) report immobilization values of lime sulfur for the cladocerans Simiocephalus serrulatus and Daphnia pulex of respectively 11 ppm and 10 ppm. These are the only available data relating to aquatic fauna. Several reports have indicated that these fungicides have caused significant mortality to beneficial insects (Pimentel, 1971). In California, Bartlett (1963) has reported lime sulfur to be toxic to parasitic wasps and predaceous coccinellids, both of which have played major roles in various biological control programs.

Copper sulfate and copper oxychloride have each produced drastic reductions in zooplankton populations when used as algicides. When used for aquatic weed control, the margin of safety for fish is small because the concentrations of these chemicals required to kill some weeds are high (DeVaney, 1968). Their acute toxicities, however, are less than those of many insecticides. We believe these compounds are hazardous only when applied directly to a waterway. Crance (1963) reported that after careful applications of copper sulfate as an algicide

(0.05-0.08 ppm) there were increased zooplankton populations, including rotifers, cladocerans, and copepods.

Nabam, at concentrations of 1 ppm, has been shown to inhibit photosynthesis of estuarine phytoplankton (Ukeles, 1962). Wadleigh (1968) indicated that fungicides are not a major cause for environmental concern, although organomercurial compounds are quite toxic to man.

Mercury has recently been the subject of concern by environmentalists and the Food and Drug Administration. It has been determined that mercury can be taken up rapidly by aquatic species and has a slow turnover time (Hanner, 1968). Moreover, the concentration found in fish tissue may be 3,000 (Johnels *et al.*, 1967) to 7,000 (Hanner, 1968) times that in the environment. The story of mercury as it emerged in the popular press was similar to the story of chlorinated hydrocarbons. However, we do not believe that mercury will be an environmental problem in the San Joaquin Valley, for two reasons: Since the total pounds reported for mercury-treated seeds includes the weight of the seeds, the actual weight of mercury is really much less. In fact, the California Department of Agriculture estimates that, where mercury-treated seeds are applied, the amount of mercury from this source is approximately 7-8 grams per acre annually. More important, the use of alkyl mercury compounds will not be reregistered by the Department for the treatment of seed grain after 1971.

Runoff from fields treated with nematocides or rodenticides is a potential pollution problem, though no deleterious environmental effects from these sources are known (Wadleigh, 1968).

Fumigants could present a problem in a local environment because they are applied at a very high rates. Thomason *et al.* (1971) have found that the most commonly used fumigants, including Telone, D-D mixture, and DBCP, were readily degraded and should not present a significant problem.

It cannot be overemphasized that only very limited information is available for assessing the environmental impact of pesticides. Useful data have been obtained for insecticides and herbicides, but not for nematocides, fungicides, or rodenticides. Significantly more information must be generated for all groups of pesticides before their effects in the aquatic environment can be adequately assessed.

Summary

This chapter reviews the literature that is available for assessing the impact of pesticides in the San Joaquin Valley. Four major conclusions can be reached from the available information:

1) Only limited information is avilable concerning the effects of pesticide use in the aquatic environment of the San Joaquin Valley.
2) Both laboratory and field data regarding effects of pesticides on primary producers and decomposers in the aquatic environment are practically non-existent, and there is little information about the effects on higher tropic levels.
3) Presently available data are insufficient to provide a more in-depth assessment of the impact of pesticides on the aquatic environment or to determine the extent to which damage might have been done to the environment.
4) On the basis of the limited evidence, the agricultural use of pesticides in the San Joaquin Valley would seem to have had no significant adverse effects upon the aquatic environment.

That is, the impact on the aquatic environment of pesticides usually seems insignificant, though more data are needed to substantiate this conclusion fully.

Few fish kills in the valley have been attributed to pesticides, and these were limited to a short period and a limited area. Also, the major kills have involved non-game fish, such as carp. However, no studies have been conducted to determine whether fish food organisms are being limited by pesticides. If zooplankton, phytoplankton, or benthic invertebrates have been suppressed or eliminated by pesticides in the environment, these effects have been undetected. Monitoring data obtained in the valley have not detected pesticide concentrations exceeding the acute toxicity levels for aquatic species. Very few monitoring data have been obtained to date, however, and periodic high concentrations may go undetected.

Proper assessment of the impact of pesticides on the aquatic environment will require an extensive monitoring program regularly maintained throughout the valley. More information will be needed on the effect of particular concentrations of pesticides on aquatic species, as well as a greater understanding of how aquatic ecosystems function.

References, Chapter 6

Alabaster, J.S. 1969. Survival of fish in 164 herbicides, insecticides, fungicides, wetting agents and miscellaneous substances. Int. Pest Contr. 11:29-35.

Allee, W.C., A.E. Emerson, O. Park, T. Park and K.P. Schmidt. 1949. *Principles of Animal Ecology*. Philadelphia, Saunders.

Allen, W.E. 1920. A quantitative and statistical study of the plankton of the San Joaquin River and its tributaries in and near Stockton, California in 1913. Univ. Calif. Publ. Zool. 22:1-292.

Anderson, B.G. 1945. The toxicity of DDT to *Daphnia*. Science. 102:539.

Anderson, B.G. 1959. The toxicity of organic insecticides to *Daphnia*. *In*: *Transactions of the Second Seminar on Biological Problems in Water Pollution*. Cincinnati, Ohio, U.S. Public Health Service. p.94-95.

Bailey, T.E. and J.R. Hannum. 1967. Distribution of pesticides in California. J. Sanit. Eng. Div., Amer. Soc. Civil Eng. 93:27-43.

Ball, R.C. and F.H. Hopper. 1966. Use of ^{74}As-tagged sodium arsenite in a study of effects of a herbicide on pond ecology. *In*: *Proceedings of a Symposium on the Use of Isotopes in Weed Research*. Vienna, International Atomic Energy Commission. p. 149-63.

Bartlett, B.R. 1963. The contact toxicity of some pesticide residues of hymenopterous parasites and coccinelid predators. J. Econ. Entomol. 56:694-98.

Bohmont, B.L. 1967. Toxicity of herbicides to livestock, fish, honeybees, and wildlife. Proc. West. Weed Contr. Conf., 20th, Salt Lake City, Utah. 21:25-27.

Bond, C.E., R.H. Lewis and J.L. Fryer. 1959. Toxicity of various herbicidal materials to fishes. *In*: *Transactions of the Second Seminar on Biological Problems in Water Pollution*. Cincinatti, Ohio, U.S. Public Health Service. p.94-95.

Braginskii, L.P. 1962. Experiment to determine the toxicity of some herbicides for aquatic invertebrates. (An abstract from: Ref. Zh. Biol., 1963. No.1 D288).

Brahinś kyyi, L.P. and L.P. Rotovś ka. 1960. Effect of herbicide 2,4-D on pond invertebrates. (An abstract from: Ref. Zh. Biol., 1961. No.6 D517).

Burdick, G.E., H.J. Dean, E.J. Harris, J. Skea, C. Frisa and C. Sweeny. 1968. Methoxychlor as a blackfly larvicide, persistence of its residues in fish and its effect on stream arthropods. N.Y. Fish Game J. 15:121-42.

Burgoyne, W.E. 1968. Studies on effects of dursban and fenthion insecticides on wildlife. Down Earth. 24:31-33.

Burke, H.R. 1959. Toxicity of several insecticides to two species of beneficial insects on cotton. J. Econ. Entomol. 52:616-18.

California Dept. of Fish and Game. 1965. California Fish and Wildlife Plan. v.3: Supporting data. Part A - Inventory of wildlife and inland fish. Sacramento, Calif.

California Dept. of Fish and Game. 1970. Fish and wildlife losses due to pesticides and pollution from 1965 to 1969. Sacramento, Calif. (A mimeograph).

California Water Resources Control Board. 1971. A review of pesticide monitoring programs in California. Report by the Ad Hoc Committee on Pesticide Monitoring, California Dept. of Agriculture. Sacramento, Calif.

Carson, R. 1961. Silent Spring. Boston, Houghton-Mifflin.

Chadwick, G.G. and R.W. Brocksen. 1970. Accumulation of dieldrin by fish and selected fish-food organisms. J. Wildl. Manage. 33:693-700.

Christie, A.E. 1969. Effects of insecticides on algae. Water Sewage Works. 116:172-76.

Clemens, H.P. and K.E. Sneed. 1959. Lethal doses of several commercial chemicals for fingerling channel catfish. U.S. Fish Wildl. Serv., Spec. Sci. Rep.--Fish. 316.

Cook, S.F. and J.D. Conners. 1963. The short-term side effects of the insecticidal treatment of Clear Lake, Lake County, California, in 1962. Ann. Entomol. Soc. Amer. 56:819-24.

Cole, H., D. Barry, D.E.H. Frear and A. Bradford. 1967. DDT levels in fish, streams, stream sediments, and soil before and after DDT aerial spray application for control of fall cankerworm in northern Pennsylvania. Bull. Environ. Contam. Toxicol. 2:127-46.

Cope, O.B. 1961. Effects of DDT spraying for spruce budworm on fish in the Yellowstone River system. Trans. Amer. Fish. Soc. 90:239-51.

Cope, O.B. 1965. Sport fishery investigations. In: The Effect of Pesticides on Fish and Wildlife. U.S. Fish and Wildlife Service. p.51-64. (U.S. Fish Wildl. Serv. Circ. 226)

Cope, O.B. 1966. Contamination of the freshwater ecosystem by pesticides. J. Appl. Ecol. 3(Suppl):33-44. (A special issue on Pesticides in the Environment and Their Effects on Wildlife).

Cope, O.B. 1971. Interactions between pesticides and wildlife. Ann. Rev. Entomol. 16:325-64.

Cope, O.B., E.M. Wood and G.H. Wallen. 1970. Some chronic effects of 2,4-D on the bluegill (Lepomis macrochirus). Trans. Amer. Fish. Soc. 99:1-12.

Cowell, B.C. 1965. The effects of sodium arsenite and silvex on the plankton populations in farm ponds. Trans. Amer. Fish. Soc. 94:371-77.

Crance, J.H. 1963. The effect of copper sulphate on Microcystis and zooplankton in ponds. Prog. Fish Cult. 25:198-202.

Crosby, D.G. and R.K. Tucker. 1966. Toxicity of aquatic herbicides to Daphnia magna. Science. 154:289-291.

Cummins, K.W., W.P. Coffman and P.A. Roff. 1966. Tropic relationships a small woodland stream. Int. J. Theor. Appl. Limnol. 16:627-37.

Cushing, C.E. and J.R. Olive. 1956. Effects of toxaphene and rotenone upon macroscopic bottom fauna of two northern Colorado reservoirs. Trans. Amer. Fish. Soc. 86:294-301.

Davis, J.T. and J.S. Hughes. 1963. Further observations on the toxicity of commercial herbicides to bluegill sunfish. Proc. S. Weed Conf. 16:337-40.

Demint, R.J., P.A. Frank and R.D. Comes. 1970. Amitrole residues and rate of dissipation in irrigation water. Weed Sci. 18:439-42.

DeVaney, T.E. 1968. Chemical vegetation control manual for fish and wildlife management programs. U.S. Bur. Sport Fish. Wildl. Resource Publ. no.48.

Dustman, E.H. and L.F. Stickel. 1966. Pesticide residues in the ecosystem. In: Pesticides and Their Effects on Soils and Water. Madison, Wis., Soil Science Society of America, Inc. p.109-21. (ASA Special Publ. no.8)

Edwards, C.A. 1970. Persistent Pesticides in the Environment. Cleveland, Ohio, CRC Press.

Federal Water Pollution Control Administration. 1968. Report of the Committee on Water Quality Criteria. Washington, Govt. Print. Off.

Fitzgerald, G.P. 1971. Algicides. Madison, Wis., University of Wisconsin Water Resources Center. (Lit. Rev. no.2).

Foy, C.L. and S.W. Bingham. 1969. Some research approaches toward minimizing herbicidal residues in the environment. Residue Rev. 29:105-35.

Frank, P.A., R.J. Demint and R.D. Comes. 1970. Herbicides in irrigation water following canal-bank treatment for weed control. Weed Sci. 18:687-92.

Gaufin, A.R., L.D. Jensen, A.V. Nebeker, T. Nelson and R.W. Teel. 1965. The toxicity of ten organic insecticides to various aquatic invertebrates. Water Sewage Works. 12:276-79.

Georgacakis, C. and M.A.Q. Khan. 1971. Toxicity of the photoisomers of cyclodiene insecticides to freshwater animals. Nature. 223:120-21.

Gilderhus, P.A. 1966. Some effects of sublethal concentrations of sodium arsenite on bluegills and the aquatic environment. Trans. Amer. Fish. Soc. 95:289-96.

Gillett, J.W., ed. 1969. The Biological Impact of Pesticides in the Environment. Corvallis, Ore., Oregon State University Press.

Godsil, P.J. and W.C. Johnson. 1968. Residues in fish, wildlife and estuaries. Pesticide monitoring of the aquatic biota at the Tule Lake National Wildlife Refuge. Pestic. Monit. J. 1:21-26.

Gould, R.F., ed. 1966. Organic Pesticides in the Environment. Washington, American Chemical Society.

Grant, C.D. 1967. Effects on aquatic insects of forest spraying with phosphamidon in New Brunswick. J. Fish. Res. Bd. Can. 24:823-32.

Green, R.S., C.G. Gunnerson and J.J. Lichtenberg. 1968. Pesticides in our national waters. In: Agriculture and the Quality of our Environment. Washington, American Association for the Advancement of Science. p.137-56. (AAAS Publ. 85)

Grzenda, A.R., G.J. Lauer and H.P. Nicholson. 1962. Insecticide contamination in a farm pond. II. Biological effects. Trans. Amer. Fish. Soc. 91:217-22.

Grzenda, A.R., H.P. Nicholson and W.S. Cox. 1966. Persistence of four herbicides in pond water. J. Amer. Water Works Ass. 58:326-32.

Hamelink, J.L., R.C. Waybrandt and R.C. Ball. 1971. A proposal: exchange equilibria control the degree chlorinated hydrocarbons are biologically magnified in lentic environments. Trans. Amer. Fish. Soc. 100:1-7.

Hannerz, L. 1968. Experimental investigations on the accumulation of mercury in water organisms. Rep. Inst. Freshwater Res., Drottingholm. 48:120-76.

Hatch, R.W. 1957. Relative sensitivity of salmonids to DDT. Prog. Fish Cult. 19:89-91.

Hawkes, H.R. 1962. Biological aspects of river pollution. In: River Pollution. 2. Causes and Effects. Edited by L. Klein. London, Butterworth.

Hawthorne, R.M. 1970. Estimated damage and crop loss caused by insect/mite pests - 1969. Sacramento, Calif., Dept. of Agriculture. (E-82-12).

Henderson, C. and Q.H. Pickering. 1958. Toxicity of organic phosphorus insecticides to fish. Trans. Amer. Fish. Soc. 87:39-51.

Henderson, C., Q.H. Pickering and C.M. Tarzwell. 1959. Relative toxicity of ten chlorinated hydrocarbon insecticides to four species of fish. Trans. Amer. Fish. Soc. 88:23-32.

Henegar, D.L. 1966. Minimum lethal levels of toxaphene as a piscicide in North Dakota lakes. U.S. Bur. Sport Fish. Wildl. Resource Publ. no.7.

Hiltibran, R.C. 1967. Effects of some herbicides on fertilized fish eggs and fry. Trans. Amer. Fish. Soc. 96:414-16.

Hooper, F.N. 1958. The effect of applications of pelleted 2,4-D upon the bottom fauna of Kent Lake, Oakland County, Michigan. Proc. N. Central Weed Contr. Conf. 15:41.

House, W.B., L.H. Goodson, H.M. Gadberry and K.W. Dockter. 1967. Assessment of Ecological Effects of Extensive and Repeated Use of Herbicides. Washington, Dept. of Commerce, Clearinghouse for Federal Scientific & Technical Information. (Rep. no.AD 824 314).

Hughes, J.S. and J.T. Davis. 1963. Variations in the toxicity to bluegill sunfish of phenoxy herbicides. Weeds. 11:50-53.

Hunt, E.G. and A.I. Bischoff. 1960. Inimical effects on wildlife of periodic DDD applications to Clear Lake. Calif. Fish Game. 46:91-106.

Hunt, E.G. and J.O. Keith. 1967. Pesticide analysis in fish and wildlife. In: Analytical Methods for Pesticides, Plant Growth Regulators and Food Additives. v.5. Edited by G. Zweig. New York, Academic Press. p.147-89.

Hunt, E.G. and J.D. Linn. 1969. Fish kills by pesticides. In: The Biological Impact of Pesticides in the Environment. Edited by J.W. Gillett. Corvallis, Ore., Oregon State University Press. p.97-102.

Ide, F.P. 1967. Effects of forest spraying with DDT on aquatic insects of salmon streams in New Brunswick. J. Fish. Res. Bd. Can. 24:769-805.

Ivie, G.W. and J.E. Casida. 1970. Enhancement of photoalteration of cyclodiene insecticide chemical residues by rotenone. Science. 167:1620-22.

Jensen, L.D. and A.R. Gaufin. 1964a. Effects of ten organic insecticides on two species of stonefly naiads. Trans. Amer. Fish. Soc. 93:27-34.

Jensen, L.D. and A.R. Gaufin. 1964b. Long-term effects of organic insecticides on two species of stonefly naiads. Trans. Amer. Fish. Soc. 93:357-63.

Johnels, A.G., T. Westermark, W. Berg, P.I. Persson and B. Sjostrand. 1967. Pike [*Esox Lucius*. *L*.] and other aquatic organisms in Sweden as indicators of mercury contamination in the environment. Oikos. 18:323-33.

Johnson, D.W. 1968. Pesticides and fishes--a review of selected literature. Trans. Amer. Fish. Soc. 97:398-424.

Johnson, W.C. 1966. Toxaphene treatment of Big Bear Lake, California. Calif. Fish Game. 52:173-79.

Kallman, B.J., O.B. Cope and R.J. Navarre. 1962. Distribution and detoxication of toxaphene in Clayton Lake, New Mexico. Trans. Amer. Fish. Soc. 91:14-22.

Keith, J.O. and M.S. Mulla. 1966. Relative toxicity of five organophosphorus mosquito larvicides to mallard ducks. J. Wildl. Manage. 30:553-63.

Kerswill, C.J. and H.E. Edwards. 1967. Fish losses after forest spraying with insecticides in New Brunswick, 1952-62, as shown by caged specimens and other observations. J. Fish. Res. Bd. Can. 24:709-29.

Kilgore, W.W. and N. Marei. 1971. Parathion in plant tissues: new considerations. A paper presented at the Simposium on Degradation of Synthetic Organic Molecules, held in San Francisco, June, 1971. (Proceedings of the National Academy of Science, in press).

Lawrence, J.M. 1958. Recent investigations on the use of sodium arsenite as an algicide and its effects on fish production in ponds. Southeast. Ass. Game Fish Comm. 11:281-86.

Lawrence, J.M. 1962. *Aquatic herbicide data*. Washington, Dept. of Agriculture. (U.S.D.A. Handbook no.231).

Lawrence, J.M. 1969. Supplement to aquatic herbicide data. U.S. Dept. of Agriculture Handbook 231.

Lindemann, R.L. 1942. The trophic-dynamic aspect of ecology. Ecology. 23:399-418.

Linn, J.D. 1968. Effects of low volume aerial spraying of dursban and and fenthion on fish. Down Earth. 24:28-30.

Linn, J.D. and R.L. Stanley. 1969. TDE residues in Clear Lake animals. Calif. Fish Game. 55:164-78.

Macek, K.J. 1969. The biological magnification of pesticide residues in the food chain. *In*: *The Biological Impact of Pesticides in the Environment*. Edited by J.W. Gillett. Corvallis, Ore., Oregon State University Press. p.17-21.

Macek, K.J. and W.A. McAllister. 1970. Insecticide susceptibility of some common fish family representatives. Trans. Amer. Fish. Soc. 99:20-27.

Macek, K.J., C. Hutchinson and O.B. Cope. 1969. The effects of temperature on the susceptibility of bluegills and rainbow trout to selected pesticides. Bull. Environ. Contam. Toxicol. 3:174-83.

Mann, K.H. 1969. The dynamics of aquatic ecosystems. Adv. Ecol. Res. 6:1-83.

Matida, Y. and N. Kawasaki. 1958. Study on the toxicity of agricultural control chemicals in relation to freshwater fisheries management. No.2. Toxicity of agricultural insecticides to *Daphnia carinata*, King. Bull. Freshwater Fish. Res. Lab., Tokyo. 8:1-6.

Mayhew, J. 1955. Toxicity of seven different insecticides to rainbow trout, *Salmo gairdnerii*, Richardson. Proc. Iowa Acad. Sci. 62:599-606.

McCraren, J.P., O.B. Cope and L. Eller. 1969. Some chronic effects of diuron on bluegills. Weed Sci. 17:497-504.

Meehan, W.R. and W.L. Sheridan. 1966. Effect of toxaphene on fishes and bottom fauna of Big Kitoi Creek, Afognak Island, Alaska. U.S. Bur. Sport Fish. Wildl. Resource Publ. no.12.

Meeks, R.L. 1967. The cycling of Chlorine-36 ring-labeled DDT in a marsh ecosystem. Ph.D. Thesis, Ohio State University.

Metcalf, R.L., G.K. Sanghu and T.P. Kapoor. 1971. Model ecosystem for the evaluation of pesticide biodegradability and ecological magnification. Environ. Sci. Technol. 5:709-13.

Miller, C.W, B.M. Zuckerman and A.J. Charig. 1966. Water translocation of diazinon-C^{14} and parathion-S^{35} off a model cranberry bog and subsequent occurrence in fish and mussels. Trans. Amer. Fish. Soc. 95:345-49.

Miller, M.W. and G.G. Berg, eds. 1969. *Chemical Fallout; Current Research on Persistent Pesticides.* Springfield, Ill., Thomas.

Mitchell, L.E. 1966. Pesticides: properties and prognoses. *In*: *Organic Pesticides in the Environment*. Edited by R.F. Gould. Washington, American Chemical Society. p.1-22.

Moore, N.W., ed. 1966. Pesticides in the environment and their effects on wildlife. J. App. Ecol. 3(Suppl.) (A special issue).

Moore, N.W. 1967. A synopsis of the pesticide problem. Adv. Ecol. Res. 4:75-129.

Mulla, M.S., J.O. Keith and F.A. Gunther. 1966. Persistence and biological effects of parathion residues in waterfowl habitats. J. Econ. Entomol. 59:1085-90.

Mullison, W.R. 1970a. The significance of herbicides to non-target organisms. Proc. Northeast. Weed Contr. Conf. 24:111-47.

Mullison, W.R. 1970b. Effects of herbicides on water and its inhabitants. Weed Sci. 18:738-50.

Muncy, R.J. and A.D. Oliver, Jr. 1963. Toxicity of ten insecticides to the red crawfish, *Procambarus clarki* (Girard). Trans. Amer. Fish. Soc. 92:428-31.

Nagvi, S.M. and D.E. Ferguson. 1970. Levels of insecticide resistance in fresh-water shrimp, *Palaemonetes kadiakensis*. Trans. Amer. Fish. Soc. 99:696-99.

Needham, R.G. 1966. Effects of toxaphene on plankton and aquatic invertebrates in North Dakota lakes. U.S. Bur. Sport Fish. Wildl. Resource Publ. no.8.

Nicholson, H.P. and D.W. Hill. 1970. Pesticide contaminants in water and mud and their environmental impact. Relat. Agr. Soil Water Pollut., Cornell Univ. Conf. 1970:171-79.

Nicholson, H.P., H.J. Webb, G.J. Lauer, R.E. O'Brien, A.R. Grzenda and D.W. Shanklin. 1962. Insecticide contamination in a farm pond. I. Origin and duration. Trans. Amer. Fish. Soc. 91:213-17.

Norris, L.A. 1968. Stream contamination by herbicides after fall rains on forest land. West. Soc. Weed Sci., Res. Prog. Rep. 1968:33-34.

O'Brien, R.D. 1967. Synergism, antagonism and other interactions. *In*: *Insecticides, Action and Metabolism*. New York, Academic Press. p.209-30.

Odum, E.P. 1959. *Fundamentals of Ecology*. Philadelphia, Saunders.

Oliver, K.H., G.H. Parsons and C.T. Huffstetler. 1966. An ecological study on the effects of certain concentrations of cacodylic acid on selected fauna and flora. Eglin Air Force Base, Fla., Air Proving Ground Center, Air Force Systems Command, U.S. Air Force.

Patterson, R.S. and D.L. vonWindeguth. 1964a. The effects of Baytex on some aquatic organisms. Mosquito News. 24:46-49.

Patterson, R.S. and D.L. vonWindeguth. 1964b. The use of Baytex as a midge larvicide. Mosquito News. 24:393-96.

Peterle, T.J. and R.H. Giles. 1964. New Tracer Techniques for Evaluating the Effects of an Insecticide on the Ecology of a Forest Fauna. Columbus, Ohio, Ohio State University Research Foundation Report.

Petruk, G.F. 1964. Effects of herbicides on heterotrophic microorganisms in ponds. Mikrobiol. 33:1018-21.

Pickering, Q.H., C. Henderson and A.E. Lemke. 1962. The toxicity of organic phosphorus insecticides to different species of warmwater fishes. Trans. Amer. Fish. Soc. 9[illegible]175-84.

Pimental, D. 1971. *Ecological Effects of Pesticides on Non-Target Species*. Washington, U.S. Govt. Print. Off.

Priester, L.E. 1965. The accumulation in metabolism of DDT, parathion and endrin by aquatic food-chain organisms. Ph.D. Thesis, Clemson University.

Ray, J. and V. Stevens. 1970. Using Baytex to control crayfish in ponds. Prog. Fish Cult. 32:58-60.

Reed, R.J. 1967. Some effects of DDT on the ecology of salmon streams in southeastern Alaska. U.S. Fish Wildl. Serv., Spec. Sci. Rep.--Fish. No.542.

Reid, G.K. 1961. *Ecology of Inland Waters and Estuaries*. New York, Reinhold Publishers.

Rudd, R.L. 1964. *Pesticides and the Living Landscape*. Madison, Wis., University of Wisconsin Press.

Rudd, R.L. and R.E. Genelly. 1956. Pesticides: Their Use and Toxicity in Relation to Wildlife. Sacramento, Calif., California Dept. of Fish and Game. (Game Bull. no.7).

Ruttner, F. 1952. *Fundamentals of Limnology*. Toronto, Quebec, University of Toronto Press.

Sanders, H.O. 1969. Toxicity of pesticides to the crustacean *Gammarus lacustus*. U.S. Bur. Sport Fish. Wildl., Tech. Papers. No.25.

Sanders, H.O. 1970. Toxicities of some herbicides to six species of freshwater crustaceans. J. Water Pollut. Contr. Fed. 42:1544-50.

Sanders, H.O. and O.B. Cope. 1966. Toxicities of several pesticides to two species of Cladocerans. Trans. Amer. Fish. Soc. 95:165-69.

Sanders, H.O. and O.B. Cope. 1968. The relative toxicities of several pesticides to naiads of three species of stoneflies. Limnol. Oceanogr. 13:112-17.

Schenk, C.F. and I. Jarolimek. 1966. Experimental aquatic weed control with endothal-silvex, diquat and simazine. Ont. Water Resource Comm., Res. Publ. no.14.

Schouwenburg, W.J. and K.J. Jackson. 1966. A field assessment of the effects of spraying a small coastal coho salmon stream with Phosphamidon. Can. Fish. Cult. 37:35-43.

Smith, G.E. and B.G. Isom. 1967. Investigation of effects of large-scale applications of 2,4-D on aquatic fauna and water quality. Pestic. Monit. J. 1:16-21.

Smith, R.L. 1966. *Ecology and Field Biology*. New York, Harper and Row.

Stewart, N.E., R.E. Milleran and W.P. Breese. 1967. Acute toxicity of the insecticide Sevin and its hydrolytic product 1-naphthol to some marine organisms. Trans. Amer. Fish. Soc. 96:25-30.

Stickel, L.F. 1968. Organochlorine pesticides in the environment. U.S. Bur. Sport Fish. Wildl., Spec. Sci. Rep.: Wildl. No.119.

Surber, E.W. and Q.H. Pickering. 1962. Acute toxicity of endothal, diquat, hyamine, dalapon and silvex to fish. Prog. Fish Cult. 24:161-71.

Thomason, I.J., C.E. Castro, R.C. Baines and R. Mankari. 1971. What happens to soil fumigants after nematode control. Calif. Agr. 25:10-12.

Tucker, R.K. and D.G. Crabtree. 1970. Handbook of toxicity of pesticides to wildlife. U.S. Bur. Sport Fish. Wildl., Resource Publ. no.84.

Ukeles, R. 1962. Growth of pure cultures of marine phytoplankton in the presence of toxicants. Appl. Microbiol. 10:532-35.

vonWindeguth, D.L. and R.S. Patterson. 1968. The effects of two organic phosphate insecticides on segments of the aquatic biota. Mosquito News. 26:377-80.

Wadleigh, C.H. 1968. Wastes in relation to agriculture and forestry. U.S. Dept. Agr., Misc. Publ. no.1065.

Walker, C.R. 1962. Toxicological effects of herbicides on the fish environment. Proc. Annu. Air Water Pollut. Conf. 8:17-34.

Walker, C.R. 1962. Simizine and other s-triazine compounds as aquatic herbicides in fish habitats. Weeds. 12:134-39.

Ware, G.W. and C.C. Roan. 1970. Interaction of pesticides with aquatic microorganisms and plankton. Residue Rev. 33:15-45.

Warnick, D.C. 1966. Growth rates of yellow perch in two North Dakota lakes after population reduction with toxaphene. U.S. Bur. Sport Fish. Wildl. Resource Publ. no.9.

Warren, C.E. 1971. *Biology and Water Pollution Control*. Philadelphia, Saunders.

Weed Society of America. 1970. *Herbicide Handbook of the Weed Science Society of America*. Urbana, Ill., The Society. (WSSA monogr.3)

Welborn, T.L. 1969. The toxicity of nine therapeutic and herbicidal compounds to striped bass. Progr. Fish Cult. 31:27-32.

West, I. 1966. Biological effects of pesticides in the environment. In: Organic Pesticides in the Environment. Edited by R.F. Gould. Washington, American Chemical Society. p.38-53.

Wilson, B.R. 1966. Fate of pesticides in the environment--A progress report. Trans. N.Y. Acad. Sci. 28:694-705.

Wilson, D.C. and C.E. Bond. 1969. The effects of the herbicides diquat and dechlobenil (Casaron) on pond invertebrates. Part I. Acute toxicity. Trans. Amer. Fish. Soc. 98:438-43.

CHAPTER 7

ALTERNATIVES TO PESTICIDES FOR PEST CONTROL

Increases in farm output of 20% have been attributed to the use of pesticides since 1940 (Shaw, 1971).

When one considers the world's burgeoning population and present levels of malnutrition, it is clear that agricultural production must be maintained at least at its present level. It is therefore necessary to keep pest populations suppressed so they will not do unacceptable damage. At the same time, the use of pesticides in agriculture is sometimes an unnecessary environmental hazard. Several techniques have been proposed to reduce environmental hazard and simultaneously maintain or increase the production level. This chapter discusses their applications in the San Joaquin Valley.

Pests are not biological entities; they are simply those species that are a nuisance or are causing economic loss. Both vertebrates and plants can be pests, but here we are concerned primarily with insects. Varley (1953) emphasized that few of the insects that feed on any plant species are economically important, although almost any species can become a pest. Major pests occur with high population densities over a large geographic area. However, spatial and temporal differences in population density must be considered in developing methods for controlling a particular species (Smith and Hagan, 1959).

The use of pesticides to control pest populations has frequently produced undesirable effects because knowledge is lacking on the interrelations of ecosystems. Pesticide use and accumulation have sometimes affected unrelated parts of the biosphere, such as the aquatic environment or predatory birds. Unanticipated and undesirable changes have taken place more often in the agro-ecosystems themselves. Areas of agricultural production are ecologically very simplified, but numerous interactions still take place between species, and efficient pest management should consider these interrelations.

The two major undesirable effects following the application of insecticides to agro-ecosystems are pest resurgence and outbreaks of secondary pests (van den Bosch, 1970a, 1971a). Pest resurgence occurs when the insecticide initially kills most members of the target population but eliminates even more efficiently the predators and parasites which are natural enemies of the target pest. Then, after a brief period of suppression the pest species frequently reappears at population densities that are higher than the original. When broad-spectrum insecticides applied against a target pest eliminate the natural enemies of previously innocuous species, secondary pest outbreaks may occur. In the absence of natural control these species increase in population density and become economic pests. Both pest resurgence and secondary pest outbreaks result directly from a decrease in the population density of predator insects following the application of broad-spectrum pesticides.

Acquiring the level of understanding necessary for proper management of pest populations will require much basic research in the areas of population and community ecology. Such research must include observations on the effect of pesticide applications on the population density of all species in the agro-ecosystem. In 1953, Varley entered a plea for biological studies to determine why certain species are pests and others are not. No such information is yet available. The necessary research will require financial support from state and federal government and from farming agencies. It will also require considerable time to be completed. In the interim, techniques are being developed that affect fewer nontarget species. Altering only a few of the species relationships in ecosystems may reduce the frequencies of undesirable effects.

One important consideration which has not been accurately assessed in the past is the extent to which a pest must be suppressed. For example, an infestation of 10 Lygus hesperus per 50 net sweeps has been used as the economic threshold for this pest in cotton in California. It has recently been shown that population densities substantially higher than this produced little or no effect on yield or fiber quality (Falcon *et al.*, 1970). Initially, insecticides seemed to be overwhelmingly successful and it was believed that eradication of pest species was possible and desirable. That goal has persisted even though it has been seldom achieved, if ever. Some control efforts have been aimed at maintaining pest populations below an economic threshold (Hagan and Smith, 1958), the level at which they cause a net economic loss. This change in attitude may result in the application of substantially lower quantities of pesticides even against pests for which no alternative means of control have been proposed. More research is now directed toward determining the establishment of economic thresholds of insect populations.

Even careful use of pesticides might have had deleterious environmental effects, and unwise use has certainly increased environmental problems. The use of pesticides is futile in some instances (e.g., against resistant mosquitoes). Once these situations are detected, pesticide use should be curtailed since continued use selects for genetically more resistant lines. To the contrary, however, pesticides have frequently been applied in greater quantities in such situations in an attempt to overcome the resistance. In other instances, pesticides have been applied against some agricultural pests in quantities that exceeded the amounts needed to control them. This occurs when pesticides are used prophylactically to prevent insect populations from acquiring pest status.

Prophylaxis in pest management is the major reason for excessive pesticide applications (Dahlsten, 1971). Azodrin was recently used in this manner against Lygus bugs in the San Joaquin Valley (van den Bosch, 1969).

Research on alternative methods of pest control increased markedly when the deleterious environmental effects of pesticides were discovered. Huffaker (1970) reported that 240 papers were published on biological control in 1955. In 1963 there were 1,400 papers, and the number has continued to increase. This chapter was compiled from approximately 300 original research articles and 25 review articles or monographs.

The need for change in pest management practicies is obvious when one considers that: there are more insect pest species today than ever before; many serious pests are resistant to pesticides; pest control costs are increasing; and environmental pollution from pesticides is increasing (van den Bosch, 1970a, 1971a). It is hoped that alternative methods of pest control will reverse these trends.

Alternative Techniques Proposed

Physical, chemical, and biological techniques have been proposed for controlling insect pests and weeds. Some of these techniques were applied more than 100 years ago but were discarded as pesticides were developed and used in greater quantities (Shea, 1971). When the environmental dangers associated with pesticide applications became evident and restrictions were placed on the use of some pesticides, research on alternative means of control increased substantially. The current status of alternative techniques was recently reviewed in articles by Busvine (1968), Knipling (1969), Holcomb (1970), Hoffman (1970), Irving (1970), and others.

Several techniques were extensively reviewed in "Pest Control" (Kilgore and Doutt, 1967). A general overview of pest management and the environmental hazards of increasing pesticide use is provided in "Scientific Aspects of Pest Control" (National Academy of Science, 1966). These reviews are the source of much of the information that follows on individual techniques. Table 7.1 lists the major alternatives that have been proposed. Research has been conducted on all

Table 7.1 Success of Pesticide Alternatives on California Crops

Crop	Pest	Alternative	Location	Success	Reference
Alfalfa	Egyptian alfalfa beetle	Integrated: Methoxychlor at 8-12 oz/acre to protect predators	Southern California	Satisfactory	Stern et al,(1962)
	Hypera brunneipennis (Egyptian alfalfa beetle)	Parasite: *Dibrachoides druso*	California	Reproduces successfully in test plots	van den Bosch, Dawson, Roth and Brown (1961)
	Colias eurytheme (alfalfa weevil)	*Bacillus thuringiensis Berliner* var. *thuringiensis*	California	Satisfactory	Hall and Stern (1962)
	Alfalfa caterpillar	Virus: *Borrelina campeoles*	California	Can be effective	Hoffman (1959b)
	Spotted alfalfa aphid	Resistant alfalfa	New Mexico	Excellent	Hoffman (1959b)
Citrus	Scale insects	Predators : coccinelids	California	Overwhelmingly successful	Hoffman (1959a)
Cotton	Insect pests	Parasite: *Trichogramma minutum* Predators: *Hippodania convergens* *Orius* sp. *Navis ferus*	Mexicali Valley, Mexico	Nearly doubled production; pesticide costs reduced more than 90%	Oliva Aleman (1961)
	Lygus bugs	Integrated	California	-cost of pesticides reduced by 75% -yield increased	van den Bosch (1971)
Grape	*Harrisina brillans* (grape skeletonizer)	Larval parasites: (*Sturmia harrisinae*, *Apanteles harrisinae*) and virus disease	California	Noneconomic damage in all infested areas Retards spread of pest	Clausen (1961)
Olive	*Parlatonia oleae* (olive scale)	Parasitic wasps: *Aphytis maculicornis*; *Coccophagoides utilis*	California	Complete	Huffaker (1971) Huffaker et al (1962)
Sunflower	Broomrape A	Resistant strains of sunflowers	Europe	97-100% resistance	Pustovoit (1960)
	Broomrape B			97-100% resistance	
	Sunflower pyralid			Complete	
	Rust			Complete	
	Downy mildew			Complete	

these techniques but many have not been tested on agricultural pests. The current status of each technique is indicated in the following descriptions.

Physical techniques

Sound: Frings and Frings (1962) and Nelson (1967) have discussed the use of sound to control insect pests. Some frequencies can be lethal at high intensities, though low frequencies are more useful as an attractant to an insect trap or a repellent. Much research is needed on the acoustical behavior of insects before this technique can be employed satisfactorily. It is probably not economically feasible to use sound for the control of agricultural pests in the field, although it may be used against stored grain or household pests.

Infrared radiation: Although infrared radiation can be used to kill pests in stored grains, it costs considerably more than fumigants and is no more effective (Busvine, 1968).

Visible light: There are many possible control methods that use visible light (Nelson, 1967). Particular frequencies can be used as attractants in light traps for some species of insect pests (Stanley and Dominick, 1958; Deay, 1961), and large-scale experiments are under way to determine the practicality of this technique. Light can be used also to upset diapause in some species (Williams *et al*., 1965; Adkisson, 1964). For example, laboratory populations of cabbageworms [*Pieris rapae*] fail to diapause if exposed to daily flashes of light for 3 to 4 hours into the dark cycle of their photoperiod (Barket *et al*., 1964). Such effects will seriously alter the life cycle of a species.

Ultraviolet light: The primary use of ultraviolet light is as an attractant in insect traps. As few as three traps per square mile substantially reduces the density of hornworm and looper populations (Knipling, 1969), and this technique may be used extensively.

Ionizing radiation: Stored-products pests can be killed by exposure to high doses of ionizing radiation, but radiation is more expensive than fumigants and has not been widely accepted. Sublethal does of ionizing radiation have been used, however, to produce sterile male insects which produce no progeny when released to mate with females in natural populations. This technique has been used to eradicate the screwworm, a livestock pest, from a 300,000-square-mile arc in the United States. Each week, 130 million sterilized screwworm flies are released (Hoffman, 1970). This program, at an annual cost of $5 million, is estimated to save ranchers $100 million per year (LaChance et al., 1967).

Cuticle abrasion: Insects are susceptible to dehydration if their waxy epicuticle can be abraded. Eberling (1961) indicated that silica aerogels can be used effectively in some cases, whereas diatomaceous earth seems ineffective (Carlson and Ball, 1962). This technique may be used for control of stored-products pests.

Flame cultivators: Liquefied petroleum gas can be used to produce a controlled flame to eliminate weeds and insect pests. The number of flame cultivators (25,000) in use throughout the United States was expected to increase because of the mounting cost of pesticide applications and public pressure against pesticide use.

Other physical techniques: Physical methods lessening the quantity of herbicides released into the environment include mowing, burning of plants, and pruning, along highways or around power lines.

Chemical Techniques

Modern broad-spectrum pesticides have caused certain environmental damage because they lack specificity. If new chemical techniques are to be substituted for pesticides, increased specificity must obviously be a primary consideration.

Pheromones: Pheromones are chemicals that are secreted into the external environment by an animal and elicit a specific response in other individuals of the same species (Shorey and Gaston, 1967). Approximately 200 insect pheromones have been discovered, of which 25 may be useful in control programs (Holcomb, 1970). Small quantities of these chemicals can be used as attractants in traps. Larger quantities may be sprayed on a field to disrupt mating behavior of pest species. Pheromones have not yet been used successfully in the control of any pest, although several research programs are investigating this possibility. The use of sex pheromones and black-light traps for control of hornworms and loopers has been especially encouraging. Recent reviews of pheromone literature include those of Shorey and Gaston (1967), Regnier and Law (1968), and Jacobsen (1965).

Juvenile hormones: Basic research on insect physiology and endocrinology has elucidated the role of hormones on growth, metamorphosis, and reproduction. Juvenile hormones are secreted by the corpora allata and prevent insect metamorphosis. These are biologically active agents which could be used to control insect pests. Williams (1967) indicated that juvenile hormones do not distinguish between beneficial and pest species, although analogues secreted by coniferous plants display considerable specificity. No practical uses have yet been developed, but this might someday become a productive field for pest control. The use of insect hormones to control pests was discussed by Ellis (1968).

Chemosterilants: Chemosterilants are chemical compounds which produce sterility in individuals of a pest species without actually killing them. These compounds may be used successfully in sterile-male programs, although additional research is needed on the development of suitable compounds, application methods, and insect mating habits (Kilgore, 1967). Some chemosterilants are mutagenic and physiologically active toward a wide variety of animals. Therefore, a thorough investigation of these compounds must be undertaken before they are applied to the natural environment (Borkovec, 1964). The available information has been reviewed in monographs by Borkovec (1966), Kilgore and Doutt (1967), and LaBrecque and Smith (1968). Although this technique is purely experimental it may become widely used.

Attractants and repellents: Various chemicals have been developed as insect attractants. These chemicals are used primarily to lure pests to traps, where they are either killed or sterilized. Repellents are chemicals which elicit avoidance reactions from a pest species. Past and present use of repellents has been reviewed by Painter (1967). It seems likely that repellents will be used most widely for temporary control in limited areas.

Antibiotics: Only preliminary laboratory experiments have been conducted on the use of antibiotics for insect control. Studies on the mode of action of antibiotics suggest they may interfere with biosynthetic pathways (Busvine, 1968).

Biological Techniques

Kennedy (1953) suggested that all pest control is biological since it involves "deliberate manipulation of a biological system called agriculture". Classical biological control involves "the action of parasites, predators, or pathogens on a host or prey population" (Stern *et al*., 1959). Several additional techniques that employ biological principles have been proposed for regulating insect populations.

Biological control (predators, parasites, and pathogens): Nearly every species in nature is attacked by predators, parasites, or pathogens. Classical biological control uses these natural enemies to produce a lower pest population density than would prevail in their absence (Stern *et al*., 1959). The first successful application of biological control followed the introduction of the predator *Rodolia cardinalis* for control of the cottony-cushion scale in California's citrus groves in 1889. Since the, cottony-cushion scale [*Icerya purchasi*] has been completely controlled by this predator in 29 countries (DeBach, 1964b). The literature on biological control was extensively reviewed in 1964 (DeBach, 1964a). More recent reviews include an article by van den Bosch (in press) and books edited by Huffaker (1971) and Clausen (in press).

Biological control is an attractive alternative because natural enemies are very specific, do not contaminate the environment, and do not need to be reapplied annually. Once a biological control agent becomes established against a particular pest, it provides permanent control of the pest (Olkowski, 1971) unless nonselective insecticides kill the control agent (Busvine, 1968). Van den Bosch (in press) indicates that biological control is "perhaps the most successful long-term suppressant of pest species of any of the insect control tactics employed by man."

Predators have provided substantial success against some pests, although parasites or parasitoides seem to offer more assurance of pest control. Most predator and parasites have been insect species introduced to be used against exotic pests, but Pimentel (1963) has suggested that many native species could also be controlled by introduced biological control agents. Briand and Welch (1961) have suggested the use of entomophilic nematodes in pest-control programs. Their data indicate that nematodes could produce substantial control of several pests, but this technique has not yet been fully developed.

Despite the numerous successes, the potential of biological control has probably not been fully exploited. The method requires the discovery of predators or parasites that might be useful, introduction of these organisms into a new habitat, evaluation of the effectiveness of the control, and distribution of successful control agents throughout the pest range (Irving, 1970).

In the United States only 20 of 520 introduced species have provided significant control against a major pest. However, a single success provides a substantial economic saving. DeBach (1962) determined that the degree of success in classical biological control is related directly to the effort expended on introducing a natural enemy. In view of past successes, this method merits increased effort.

The use of pathogens as a control agent is much more recent than the use of predators or parasites. During the past 20 years, however, several field tests have successfully employed microbial pesticides against insect pests (Tanada, 1967). The outstanding success involved the use of milky spore disease against the Japanese beetle. Effective use of pathogens is currently limited to a few pest species, but further research may increase this number.

The first commercial virus, VIRON/H, was registered by the USDA on December 9, 1970, and used on a large scale for the first time in 1971 (Greer et al., 1971). This virus is specific for members of the genus Heliothis and is used primarily against cotton bollworms. Field tests of the virus have obtained better control than with insecticides 80-90% of the time, and in some areas the virus can replace insecticides completely. Although the results of large-scale applications have not been analyzed yet, viral pesticides may be an important new means of pest control. Over 300 insect viruses are known that can be applied against specific insect species.

There has been some concern that viruses or bacteria used to control pest populations could infect man. Such seems unlikely, though caution should be exercised (Steinhaus, 1959). These pathogens have very specific host requirements; and because of such specificity should pose less hazard than chemical insecticides.

An important aspect of biological control that has been ignored until recently concerns the naturally occurring control of natural species (Huffaker, 1971). Recent work in California (Hagen et al., 1971) indicates that many potential agricultural pests are being controlled by natural enemies. Consequently, whatever controls are used to replace pesticides, care must be taken to maintain these native biological control agents. Natural control of several insect species, including cottony—cushion scale, citrus red mite, California red scale citrus mealybugs and long-tailed mealybugs in California, has been upset by pesticide application for other pests (DeBach and Bartlett, 1951; Bartlett and Solomon, 1953; Bartlett, 1957).

Competitors: The establishment of a harmless ecological competitor to displace a pest species has been suggested (Doutt, 1967), but limited understanding of agro-ecosystems probably prohibits use of this technique at present.

Pest-resistant crops: Sophisticated breeding programs have been developed to produce pest-resistant plants. Resistance can occur because plants deter insects from attacking them, suppress or destroy the insects, or tolerate the insects without loss of vigor or yield (Busvine, 1968). Practical successes have been obtained from some crops against several serious pests including aphids, weevils, and leafhoppers (Hoffman, 1970). Further successes may be expected because of our increasing knowledge of genetic interactions, but it usually takes at least 10 years to develop acceptable resistant varieties (Hoffman, 1970).

Genetic manipulations: There have been several proposals for introducing deleterious genes into natural insect populations. This ingenious technique is receiving some support, but is still very speculative and may be successful only against small and isolated populations (Busvine, 1968).

Sterile male: The mass release of laboratory-reared sterilized male insects has been responsible for extermination of the screwworm throughout the United States. Since this technique depends on overwhelming the wild insects with vigorous sterile males, the pest must be sterilized without seriously affecting its sexual vigor or longevity. Control of screwworm has been extraordinarily successful but the technique is limited to pests which can be easily reared in the laboratory and occur in nature at relatively low population densities (Irving, 1970).

Cultural Control

Cultural methods have long been important in insect control. These methods involve spatial or temporal manipulations of the crop and include the destruction of plant parts left in the field after harvest, crop rotation, and early or delayed planting to avoid high emerging insect populations. Van den Bosch (in press) indicated that only cultural control compares with biological control as a successful long-term means of pest management. Four outstanding examples of cultural control follow:

1) In Idaho, the beet leafhopper [Circulifer tenellus] was causing substantial damage to the sugar beet crop. It is known that the beet leafhopper overwinters in Russian thistle (McCaull, 1971). This alternate host plant was destroyed and replaced in useful forage grasses, so the pest species can no longer reproduce (Knipling, 1969).

2) In 1961, $4 million were being spent annually to spray insecticide resistant grape leafhoppers in California (Spencer, 1971). Although this pest could be controlled by the predator wasp Anagrus epos, the predator disappeared during the winter. It was determined that the wasp overwintered on blackberry bushes, which were then planted near the vineyards. According to Dr. Richard L. Doutt, Professor of Entomology at U. C. Berkeley, as little as 1/5 acre of blackberries provides enough wasps to control grape leafhopper on a 3,000-acre vineyard.

3) Perhaps the outstanding example of cultural control involves Lygus bugs in cotton in California (Stern et al., 1964, 1967; van den Bosch et al., 1971). Alfalfa [Medicago sativa] is a preferred host of Lygus bugs, and interplanting alfalfa strips in cotton fields has proved a very effective control

tactic in both experimental and commercial fields. A 16-to-32-foot strip of alfalfa is sufficient to keep Lygus bugs out of 300-400 feet of cotton. This technique is rather easy to employ and may receive wide application in the next few years.

4) A farmer in California has successfully grown 3,000 acres of tomatoes without using any pesticides, simply by planting and harvesting early (Allen, 1971). The major pest outbreaks on tomatoes occur during September in California, but proper timing of crops permits harvesting to occur before then.

Cultural control practices suppress pest populations substantially. Human manipulation is a constant need, however, and additional techniques must often be employed for complete control.

Integrated Control

As defined by Stern et al. in 1959, integrated control is "applied pest management which combines and integrates biological and chemical control." Since that time, integrated control systems have utilized all suitable techniques to reduce pest populations and maintain them below their economic threshold (van den Bosch et al., 1971). The problems that resulted from use of insecticides illustrates that we cannot control a given pest alone but must consider the ecosystem in which that pest exists (Doutt and Smith, 1971). Sophisticated pest control requires a thorough understanding of the biology, ecology, and population dynamics of the insects to be controlled and other species in the agroecosystem. A given ecosystem must be manipulated on the basis of ecological information, such that no method of control disrupts any other control (Reynolds, 1971). For many pests, however, information is lacking on the life history, host plants, dispersal patterns, population dynamics, role of natural enemies and numerous other characteristics (Irving, 1970). There are some outstanding examples of successful integrated control programs (van den Bosch et al., 1971; Hoyt and Caltagirone, 1971), but such programs require extensive preliminary research and extended observation periods. Integrated control programs offer the most rational approach to pest control, though their development and implementation will require substantial financial support.

Alternative Techniques for Crops of the San Joaquin Valley

The preceding section provides an extensive, though by no means exhaustive, listing of proposed alternatives to pesticides. The potential of some of these techniques has not been established. Most will probably not have widespread application but be applicable only to particular situations. Table 7.2 lists specific alternatives that have been field-tested on crops that are grown in the San Joaquin Valley, and indicates their success where studied. Techniques tested in other regions may have different success in the valley. For example, *Bathyplectes curculionis* provides excellent control of alfalfa weevils in Utah and Yuma Valley but fails in the San Joaquin Valley because it cannot withstand the hot summers (van den Bosch *et al.*, 1971). Even though the extent of control may differ, techniques have been listed to indicate that they have been field-tested and may be a possible alternative.

Table 7.2 shows that alternative techniques have been applied against numerous pests of field crops, seed crops, fruit and nut crops, and vegetable crops. The techniques employed include cultural control, predators, parasites, virus and bacteria diseases, resistant plants, and integrated control programs. The most successful alternative to pesticides until recently has been various forms of biological control. Integrated control programs have recently been established for alfalfa, cotton, and grapes, and substantial progress has been made on programs in citrus, apples, walnuts, peaches, and woody ornamentals (van den Bosch, 1971b). Evaluating the success of alternative techniques is very difficult. Clearly, the use of alternative techniques has lowered the

Table 7.2 Some Applications of Alternative Techniques to Crops Grown in the San Joaquin Valley

Crop	Pest	Alternative	Location	Success	Reference
Alfalfa	Spotted alfalfa aphid (Therioaphis maculata)	Pest-resistant alfalfa	New Mexico	Excellent	Hoffman, 1959b
		Pest-resistant varieties		Nearly complete immunity to attack	Knipling, 1969
		Integrated: native predators, introduced predators, entomogenous fungi and selective insecticides	California	Successful throughout California	Snuth and Hagen, 1959 Stern and van den Bosch, 1959
				Savings of $10 million annually	van den Bosch, 1971b
	Alfalfa caterpillar (Colias eurytneme)	Biological: pathogen virus, Borrelina campeoles	California	Can be effective, but not reliable	Hoffman, 1959b
		bacteria, Bacillus thuringiensis	California	Satisfactory, less effective than viruses	Hall and Stern, 1962 Steinhaus, 1951
	Alfalfa weevil (Hypera postica)	Cultural: insecticide treatment of stubble after harvest	Wyoming	84-99% reduction in larval numbers	Pfadt and Larigne, 1964
		Integrated: proper timing of insecticide application to avoid killing parasites	Indiana	Satisfactory	Wilson and Armbrust, 1970
		Biological: parasite Bathyplectes curculionis	California	Reduced to minor pest status	van den Bosch and Marble, 1971
	Egyptian alfalfa weevil (Hypera brunneipennis)	Biological: parasite Dibrachoides druso	California	Parasite established in test plots but not particularly effective	van den Bosch, et. al., 1961
		Bathyplectes curculionis	Yuma Valley, Arizona	Successful (not in San Joaquin Valley)	van den Bosch, et. al., 1971b
		B. anurus	California	Increasing in number but success undetermined	
		Microctonus aethiops, M. cokei, Patasson sp., B. stenostigma	California	Released in alfalfa fields but success undetermined	
		Integrated: Methoxychlor at 8-12 oz/acre to protect predators. Predators: Hippodamia convergens Orius tristicila Nabis ferus Parasites: Praon palitans Trioxys utilis Aphelinus semiflavus	Southern California	Satisfactory	Stern, et. al., 1962
Almonds	Navel orangeworm	Biological: pathogen Bacillus thuringiensis	California	Unsuccessful	Summers and Price, 1964
Cabbage	Insect Pests: Cabbage looper (Trichoplusia ni) Imported cabbageworm (Pieris rapae) Diamondback moth (Plutella maculipennis) Fall armyworm (Sporoptera frugipercia)	Biological: pathogens bacteria, B. thuringiensis spray	S. Carolina	Controls all but cabbage looper	Creighton, et. al., 1970
		B. thuringiensis dust		Effective control of all four prsts	
		Virus, nuclear polyhedrosis		Effective control of all four pests	
		Both pathogens		Comparable to best insecticides	
Citrus	Scak insects	Biological: predators Coccinelid	California	Overwhelmingly successful	Hoffman, 1959a
	Purple scale (Lepidosaphes beckii)	Biological: parasite Aphytis lepidosaphes	Southern California	Partial control	DeBach and Landi, 1961
		Integrated: parasites and oil spray for mites	Southern California	Control comparable to or better than insecticides at less than half the cost	
	Soft (brown) scale (Coccus hesperidum)	Biological: native predators Metaphycus luteolus	California	Maintained below economic threshold unless predators are killed by insecticide drift from adjacent crops	Bartlett and Ewart 1951

Table 7.2 - Continued

Crop	Pest	Alternative	Location	Success	Reference
	Citrus mealybugs (*Pseudoccus citri*)	Biological: native predators *Crytolaemus montrouzieri* *Leptomastidea abnormis*	Southern California	Maintained below economic threshold unless predators are killed by insecticide drift from adjacent crops	Bartlett, 1957
Cole crops	Cabbage looper (*Trichoplusia ni*)	Biological: pathogens *Bacillus thuringiensis* and polyhedrosis virus	Texas	Significant reduction in 7 days	Wolfenbarger, 1965
		Biological: pathogens virus virus with insecticide	Washington	Significant mortality Slightly better control than viruses alone	Getzin, 1962
		Integrated: viruses and organophosphorus insecticides	Maryland	Excellent	Woodall and Ditman, 1967
Corn	European cornborer (*Costrinia nubilalis*)	Biological: pathogen *Bacillus thuringiensis*	Quebec	Slightly superior to insecticides	Hudon, 1963
Cotton	Cotton bollworm (*Heliothis zea*)	Biological: pathogen VIRON/TM	Texas	More successful than insecticides in 80-90% of experimental cases	Greer, *et. al.*, 1971
		Biological: pathogen *Bacillus thuringiensis*	California	Inhibits larval feeding and disrupts development but does not immediately kill pest	Falcon, *et.al.*, 1965
		Biological: native predators *Geocoris pulleus* *Nabis americoferus* *Chrysopa carnea*	California	Reduce bollworm populations approximately 50% more than 50% more than 50%	van den Bosch, *et.al.*, 1969
	Pink Bollworm	Sterile - male, pheromones to live males to traps, sterilization with radioactive cobalt	San Joaquin Valley	Has successfully prevented this pest from becoming established in the Valley	Hoffman, 1970
	Insect pests	Biological: parasites and predators *Trichogamma minutum*, *Hippodamia convergens*, *Orius* sp., *Navis ferus*	Mexico	Yield doubled and pest control costs were reduced by 90%	Oliva Aleman, 1961
	Lygus bugs (*Lygus hesperus*)	Biological: Native predators compared to pesticides	California	Only one pesticide program produced a greater yield than the untreated control	Falcon, *et.al.*, 1968
		Integrated	California	Excellent yield at greatly reduced costs	van den Bosch, *et.al.*, 1971a
Deciduous orchards	Olive Scale (*Parlatoria oleae*)	Biological parasites *Aphytis maculicornis*, *Coccophagoides utilis*	California	Complete control	Kennett, 1967
Grapes	Grape leaf skeletonizer (*Harrisina brillians*)	Biological: pathogens *Bacillus thuringiensis*	California	Intermittent success	Hall, 1955
		Biological: parasites *Sturmia harrisinae*, *Apanteles harrisinae*	California	Suppression to noneconomic level	Clausen, 1961
	Grape leaf folder (*Desmia funeralis*)	Biological: pathogen *Bacillus thuringiensis*	California	Usually as effective as insecticides without killing natural enemies of other pests	Jensen, 1969
	Omnivorous leaf roller	Cultural, disking and removal of diseased clusters	San Joaquin Valley	Provides better control than insecticides	Lynn, 1969
	Spider mites (*Eotetranychus willamettei*) (*Tetranychus pacificus*)	Biological: native predator *Metaseiulus occidentalis*	San Joaquin Valley	Broad spectrum pesticides produced pest outbreak, balance being restored with selective acaricides	Flaherty, *et.al.*, 1969
Olives	Olive scale (*Parlatoria oleae*)	Biological: parasites *Aphytis maculicornis*, *Coccophagoides utilis*	California	Complete control	Huffaker, *et.al.*, 1962 Kennett, *et.al.*, 1965

Table 7.2 - Continued

Crop	Pest	Alternative	Location	Success	Reference
Peaches	Oriental fruit moth	Biological: parasites	California	Unsuccessful	Hoffman, 1959a
	Insect pests	Integrated	California	Promising	Hoyt and Caltagirone, 1971
Pears	Pear psylla	Biological: parasites *Antho coris antevolens*, *Chrysopa plorobunda*, *Hemerobims angustus*, *Trechnites insidiosus*	California	As effective as insecticides against psylla but fruit damaged by coddling moth	Madsen and Wong, 1964
Strawberries	Two-spotted spider mites (*Tetranychus urticae*)	Biological predator *Phytoseiulus persimilis*	California	Satisfactory	Oatman, 1965
	Cyclamen mite (*Tarsonemus pallidus*)	Biological: predators *Typhlodromus reticulatus* *T. cucumeris*	California	Provides satisfactory control if not disrupted by insecticides applied against other pests	Huffaker and Kennett, 1953
Sugar Beets	Beet leafhopper	Cultural: destruction of alternate host	Idaho	Successful control over large areas	Knipling, 1969
Sunflower	Sunflower moth (*Homoeosoma electellum*)	Biological: pathogen *Bacillus thuringiensis*	California	Insufficient control	Carlson, 1968
	Broomrape A Broomrape B Sunflower pyralid Rust Downy mildew	Pest-resistant varieties	Europe	97-100% resistance 97-100% resistance Complete resistance Complete resistance Complete resistance	Pustovoit, 1960
Tomatoes	Tomato fruitworm (*Heliothis zea*)	Biological: predator	San Joaquin Valley	Reduced pesticide cost from $35 per acre to 0-$8 per acre for 4000-acre ranch	Spencer, 1971
		Biological: pathogen *Bacillus thuringiensis*	California	No damage to fruit from pest	Shorey and Hall, 1963
	Tomato horn worm	Biological: parasite *Polistes* sp.	N. Carolina	Suppresses below economic threshold	Hoffman, 1959a
		Biological: pathogen *Bacillus thuringiensis*	Carolinas	Comparable to insecticides but does not control other pests	
	Cabbage looper (*Trichoplusia ni*)	Biological: pathogen *Bacillus thuringiensis*	California	Satisfactory	Shorey and Hall, 1963
	Beet armyworm (*Spodoptera exiqua*)			Satisfactory	
	Potato aphid (*Macrosiphum euphorbiae*)			Unsatisfactory	
	Western flower thrips (*Frankliniella occidentalis*)			Unsatisfactory	
	Leafminers (*LiriomyZa spp.*)			Unsatisfactory	
Walnut	Walnut aphid (*Chromophis juglandicola*)	Biological: predator	California	Complete control	van den Bosch (in press)
Wheat	Hessian Fly	Pest-resistant varieties	Kansas	Virtual immunity to pest damage	Knipling, 1969

quantity of pesticides being released into the environment. Although the magnitude of success of these methods is difficult to assess, they have provided a more economical means of pest control. The following two examples will indicate the economic importance of these techniques:

1) In 1955 the spotted alfalfa aphid, an exotic species introduced from Mexico, caused losses in California alfalfa of nearly $13 million. When this insect developed resistance to insecticides an integrated control program was developed for its control (van den Bosch, 1971b). This program was implemented in 1958, and losses fell to less than $2 million. Spotted alfalfa weevil is no longer considered a major pest species (Hawthorne, 1970). If annual savings during this period average $10 million, the total value of the program to date is $140 million.

2) An even greater success occurred with cottony-cushion scale. In 1887 the entire citrus industry of California was threatened with destruction by cottony-cushion scale [Icenrya purchasi], which had been introduced into California in 1868 (DeBach et al., 1971). The vedalia lady-beetle [Rodolia cardinalis] was introduced in 1888 and completely suppressed the scale by 1889 (Pouth, 1958). Recent studies indicate that cottony-cushion scale is still controlled by vedalia beetles (DeBach et al., 1971), although this control is frequently disrupted by the spraying of orchards for other pest species (DeBach and Bartlett, 1951). The orange crop alone was valued at over $108 million in 1970. There were also substantial income from grapefruit, lemons, and tangerines (California Department of Agriculture, 1970). More than 110,000 acres in the San Joaquin Valley grow citrus crops at an estimated value of $1,815 per acre. These figures give some indications of the economic value of the vedalia beetle.

Estimating the economic savings from alternative methods is complicated by natural temporal differences in pest density. For instance, spotted alfalfa weevil might not have been an economic pest in any of the past fourteen years even without the integrated control program. No one can say what damage would have occurred in the absence of the alternative. Furthermore, once a pest is controlled there is a tendency to forget that it may re-emerge as a pest in the future (Olkowski, 1971). We estimate the damage from pest species but do not consider the savings that result from controlling species so they do not become pests. DeBach (1964c) estimated that 5 major biological control programs produced savings in excess of $110 million in California in 1923-1959.

Prospect of Change

Alternative techniques will be used more in the future, although a substantial increase will probably not occur soon. Contributing to increased interest in alternative techniques are economics and the deleterious environmental effects from pesticides. Many of these alternatives are yet to be refined, however, and will not be practical for field application for several years (van den Bosch, 1970a). Even techniques that can provide satisfactory pest control may not be employed by farmers until they become an economic necessity (McCaull, 1971; van den Bosch, 1971c).

Several changes are still needed before substantially fewer pesticides are applied to agricultural commodities. The primary concern of the farmer is to make as much profit on his crops as possible. This generally requires that he raise crops with minimal pest damage. Many farmers obtain advice on pest control from representatives of the pesticide manufacturer (van den Bosch, 1971c). The representatives want to sell pesticides and recommend pesticides even if feasible alternatives are available. They frequently advise farmers to apply pesticides even if damage from pests is unlikely. Berg (1971) has indicated a feedback effect: that whatever the results of a pesticide application, larger amounts are likely to be used in future applications. Alternative methods may achieve substantial acceptance only when they are as easy to employ as pesticides (Grabow, 1971). It will also be necessary to provide information for the farmer as efficiently as now done by pesticide manufacturers.

The nature of alternative techniques indictates that significant changes in pest control will occur only if supported by governmental agencies. Substantial profits can be made from pesticide sales but not from the sale of alternative techniques (Olkowski, 1971). Consequently, there is no incentive for private enterprise to develop alternatives. Biological and integrated control programs have some supporters at both state and federal levels, though little financial support. Senate Bill S 1794, introduced by Senator Gaylord Nelson on May 6, 1971, would allocate $4 million for "developing and testing the control of agricultural and forest pests by the employment of integrated biological-cultural means." If this bill passes it will provide a significant stimulus for increased application of alternative techniques. At the state level, the Assembly Committee on Environmental Quality held a hearing on November 10, 1971, to discuss integrated control. This is the first such hearing ever held in California. Its significance cannot be estimated at this time, though the increased awareness of the need for alternative means of pest control is encouraging.

For control of some pests, techniques are available that are more economical than pesticides. Development of additional methods of pest control will require financial support and time for research and field testing. Utilization of available techniques is not primarily a scientific concern; rather, it requires economic, social, and political changes that may be difficult to produce. It may be that acceptance of alternative methods of pest control will occur only if environmental harm from pesticide use increases or pesticide costs becomes unbearable.

Reference, Chapter 7

Abeling, W. 1961. Physico-chemical methods for the removal of insect wax by means of finely divided powders. Hilgardia 30:531-61.

Adkisson, P.L. 1964. Action of the photoperiod on controlling insect diapause. Amer. Natur. 98:357-64.

Allen, F. 1971. Statement on integrated control, presented at a Hearing before the California Assembly Environmental Quality Committee. Sacramento, Calif., Nov. 10, 1971.

Barker, R.J., C.F. Cohen and A. Mayer. 1964. Photoflashes: A potential new tool for control of insect populations. Science 145:1195-97.

Bartlett, B.R. 1957. Biotic factors in natural control of citrus mealybugs in California. J. Econ. Entomol. 50:753-55.

Bartlett, B.R., and W.H. Ewart. 1951. Effect of parathion on parasites of _Coccus hesperidum_ L. J. Econ. Entomol. 44:344-47.

Berg, G.G. 1969. Discussion following presentation by R.L. van den Bosch. p. 111 In: Chemical Fallout. Edited by M.W. Miller, G.G. Berg, Springfield, Ill., Thomas.

Borkovec, A.B. 1964. Insect chemosterilants: their chemistry and application. Residue Rev. 6:87-103.

Borkovec, A.B. 1966. Insect chemosterilants. Published as Vol. VII of the Advances in Pest Control. Edited by R.L. Metcalf, New York, Wiley/ Interscience.

Briand, L.J. and H.E. Welch. 1961. Use of entomophilic nematodes for insect pest control. Phytoprotection 44:37-41.

Busvine, J.R. 1968. Insecticide resistence and the future of pest control. PANS 14:310-28.

California Dept. of Agriculture. 1970. A Report on California's Principle Crop and Livestock Commodities. Sacramento, Department of Agriculture.

Carlson, E.C. 1968. Control of sunflower moth larvae and damage to sunflower seeds. Calif. Agr. 22(7):6-8.

Carlson, S.D. and H.J. Ball. 1962. Mode of action and insecticidal value of diatomaceous earth as a grain protectant. J. Econ. Entomol. 55:964-70.

Clausen, C.P. 1961. Biological control of western grape leaf skeletonizer (_Harrisina brillians_) in California. Hilgardia 31:613-38.

Clausen, C.P. (Editor and contributor). A world review of parasites, predators, and pathogens introduced to new habitats. Washington, U.S. Department of Agriculture (In press).

Creighton, C.S., T.L. McFadden, and J.V. Bell. 1970. Pathogens and chemicals tested against caterpillars on cabbage. U.S. Dept. Agr. Prod. Rec. Rep. 114:1-10.

Dahlsten, D.L. 1971. Statement on integrated control, presented at a Hearing before the California Assembly Environmental Quality Committee. Sacramento, Calif., Nov. 10, 1971.

Deay, H.O. 1961. Use of light traps to control insects. U.S. Dept. Agr. ARS 20-10.

DeBach, P. 1962. An analysis of successes in biological control of insects in the Pacific area. HawaiianEntomol. Soc. 18:35-45.

DeBach, P. (ed.) 1964a. Biological Control of Insect Pests and Weeds New York, Reinhold.

DeBach, P. 1964b. Successes, trends, and future possibilities. In: Biological Control of Insect Pests and Weeds. Edited by Paul DeBach, New York, Reinhold. p. 673-713.

DeBach, P. 1964c. The scope of biological control. In: Biological Control of Insect Pests and Weeds. Edited by Paul DeBach, New York, Reinhold. p. 1-20.

DeBach, P. and B.R. Bartlett. 1951. Effects of insecticides on biological control of insect pests of citrus. J. Econ. Entomol. 44:372-83.

DeBach, P. and J. Landi. 1961. The introduced purple scale parasite, Aphytis lepidosaphes Compere, and a method of integrating chemical and biological control. Hilgardia 31:459-97.

DeBach, P., D. Rosen and C.E. Kennett. 1971. Biological control of coccids by introduced natural enemies. In: Biological Control. Edited by C.B. Huffaker, New York, Plenum Press. p. 165-94.

Dethier, V.G., L.B. Browne and C.N. Smith. 1960. The designation of chemicals in terms of the responses they elicit from insects. J. Econ. Entomol. 53:134.

Doutt, R.L. 1958. Vice, virtue and the vedalia. Bull. Entomol. Soc. Amer. 4:119-23.

Doutt, R.L. 1967. Biological control. In: Pest Control: Biological, Physical, and Selected Chemical Methods. Edited by W.W. Kilgore and R.L. Doutt. New York, Academic Press. p. 3-30.

Doutt, R.L. and R.F. Smith. 1971. The pesticide syndrome - diagnosis and suggested prophylaxis. *In*: *Biological Control*. Edited by C.B. Huffaker, New York, Plenum Press. p. 3-15.

Ellis, P. 1968. Can insect hormones and their mimics be used to control pests? PANS (Pest Articles and News Summaries) 14:329-42.

Falcon, L.A., T.F. Leigh, R. van den Bosch, J.H. Black and V.E. Burton. 1965. Insect diseases tested for control of cotton bullworm. Calif. Agr. 19(7):12-14.

Falcon, L.A., R. van den Bosch, C.A. Ferris, L.K. Stromberg, L.K. Etzel, R.E. Stinner and T.F. Leigh. 1968. A comparison of season-long-cotton-pest-control programs in California during 1966. J. Econ. Entomol. 61: 633-42.

Falcon, L.A., R. van den Bosch, J. Gallagher and A. Davidson. 1971. Investigations of the pest status of *Lygus hesperus* in cotton in central California. J. Econ. Entomol. 64: 56-61.

Flaherty, D.L., C.D. Lynn, F.L. Jensen and D.A. Luvisi. 1969. Ecology and integrated control of spider mites in San Joaquin vineyards. Calif. Agr. 23(4):11.

Frings, H. and M. Frings. 1962. Pest control with sound: Part 1. Possibilities with invertebrates. Sound 1(6):13-20.

Grabow, H. 1971. Statement on integrated control, presented at a Hearing before the California Assembly Environmental Quality Committee, Sacramento, Calif., Nov. 10, 1971.

Getzin, L.W. 1962. The effectiveness of the polyhedrosis virus for control of the cabbage looper, *Tricho plusia ni*. J. Econ. Entomol. 55:442-45.

Green, F., C.M. Ignoffo and R.F. Anderson. 1971. The first viral pesticide: a case history. Chem. Tech. 1971:342-47.

Hagan, K.S. and R.F. Smith. 1958. Chemical and biological methods of pest control. Agr. Chem. 13:30-32, 89.

Hall, I.M. and V.M. Stern. 1962. Comparison of *Bacillus thuringiensis* Berliner var. Thuringiensis and chemical insecticides for control of the alfalfa caterpillar. J. Econ. Entomol. 55:862-65.

Hawthorne, W. 1970. Estimated damage and crop loss caused by insect/mite pests. Calif. Dept. of Agr. Rep. to County Agr. Comm. Issued Nov. 6, 1970.

Hoffman, C.H. 1959a. Biological control of noxious insects, weeds. Part I. Agr. Chem. 14(3):47-48, 91.

Hoffman, C.H. 1959b. Biological control of noxious insects, weeds. Part II. Agr. Chem. 14(4):33-34, 135.

Hoffman, C.H. 1970. Alternatives to conventional insecticides for control of insect pests. Agr. Chem. 25(9):14-23, 35.

Holcomb, R.W. 1970. Insect control: Alternatives to the use of conventional pesticides. Science. 168:456-58.

Hoyt, S.C. and L.E. Caltagirone. 1971. The developing programs of integrated control of pests of apples in Washington and peaches in California. *In*: *Biological Control*. Edited by C.B. Huffaker, New York, Plenum Press. p. 395-421.

Hudon, Marcel. 1963. Further field experiments on the use of *Bacillus thuringiensis* and chemical insecticides for the control of the European cornborer, *Ostrinia nubilalis* on sweet corn in southwestern Quebec. J. Econ. Entomol. 56:804-8.

Huffaker, C.B. 1970. "Life against life - Nature's pest control scheme." Environ. Res. 3:162-75.

Huffaker, C.B. (ed.). 1971a. *Biological Control*. New York, Plenum Press.

Huffaker, C.B. 1971b. Preface to *Biological Control.* Edited by C.B. Huffaker, New York, Plenum Press.

Huffaker, C.B. and C.E. Kennett. 1953. Developments toward biological control of ajclamen mites on strawberries in California. J. Econ. Entomol. 46:802-12.

Huffaker, C.B., C.E. Kennett and G.L. Finney. 1962. Biological control of olive scale, *Parlatoria oleae* (Colvee) in California by imported *Aphytis maculicornis* (Masi) (Hymenoptera: Aphelinidae) Hilgardia 32:541-636.

Irving, G.W., Jr. 1970. Agricultural pest control and the environment. Science. 168:1419-24.

Jacobsen, M. 1965. *Insect Sex Attractants*. Interscience Publishers, New York, p. 154.

Jensen, F.L. 1969. Microbial insecticides for control of grape leaf folder. Calif. Agr. 23(4):5-6.

Kennedy, J.S. 1953. Insect population balance and chemical control of pests: Biological Control. Chem. and Ind. 1953:1329.

Kennett, C.E. 1967. Biological control of olive scale, *Parlatoria oleae* [Colvee] in a deciduous fruit orchard in California. Entomophaga 12:461-74.

Kennett, C.E., C.B. Huffaker and K.W. Opitz. 1965. Biological control of olive scale. Calif. Agr. 19(2):12-15.

Kilgore, W.W. 1967. Chemosterilants in *Pest Control*. Edited by W.W. Kilgore and R.L. Doutt, New York, Academic Press. p. 197-239.

Kilgore, W.W. and R.L. Doutt (eds.) 1967. Pest Control, New York, Academic Press.

Knipling, E. F. 1969. Alternative methods of controlling insect pests. FDA Papers 3:16-18, 23-24.

LaBrecque, G.C. and C.N. Smith. 1968. Principles of Insect Chemosterization. New York, Appleton-Century-Crofts.

LaChance, L.E., C.H. Schmidt and R.C. Bushland. 1967. Radiation induced sterilization. In: Pest Control. Edited by W.W. Kilgore and R.L. Doutt, New York, Academic Press. p. 147-196.

Lynn, C.D. 1969. Omnivorous leaf roller, an important new grape pest in the San Joaquin Valley. Calif. Agr. 23(4):16-17.

Mc Caull, J. 1971. Know your enemy. Environment 13:30-39.

Madsen, H.F. and T.T.Y. Wong. 1964. Effects of predators on control of pear psylla. Calif. Agr. 18(2):2-3.

National Academy of Sciences. 1966. Scientific Aspects of Pest Control. Washington, The Academy.

Nelson, S.O. 1967. Electromagnetic energy. In: Pest Control. Edited by W.W. Kilgore and R.L. Doutt. New York, Academic Press. p. 89-145.

Oatman, E.R. 1965. Predacious mite controls two-spotted spider mite on strawberry. Calif. Agr. 19(2):6-7.

Oliva-Aleman, J. 1961. Possibilities of biological control of cotton pests in the agricultural region of the Mexicali Valley. Fitofilo 14(32): 25-28.

Olkowski, W. 1971. Statement on biological control, presented at a hearing before the California Assembly Environmental Quality Committee. Sacramento, Calif., Nov. 10, 1971.

Painter, R.R. 1967. Repellents. In: Pest Control. Edited by W.W. Kilgore and R.L. Doutt, New York, Academic Press. p. 267-85.

Pfadt, R.E. and R.J. Lavigne. 1964. Alfalfa weevil control by stubble treatment. J. Econ. Entomol. 57:996-97.

Pimentel, D. 1963. Introducing parasites and predators to control native pests. Can. Entomol. 95:785-92.

Pustovoit, V.S. 1960. Methods for finding varieties of sunflower immune to the principal diseases and pests. Referat. Zhur. Biol. No. 22G627.

Regnier, F.E. and J.H. Law. 1968. Insect pheromones. J. Lipid Res. 9: 541-51.

Reynolds, H.T. 1971. Statement on integrated control, presented at a Hearing before the California Assembly Environmental Quality Committee, Sacramento, Calif. on Nov. 10, 1971.

Shaw, W.C. 1971. How Agricultural Chemicals Contribute to our Current Food Supplies. *In*: Agricultural Chemicals - Harmony or discord for food, people, environment. Edited by J.E. Swift, Berkeley, Calif., Div. of Agr. Sci., U.C., p. 18-24.

Shea, K.P. 1971. Old weapons are best. Environment 13:40-49.

Shorey, H.H. and L.K. Gaston. 1967. Pheromones *In*: *Pest Control*. Edited by W.W. Kilgore and R.L. Doutt, New York, Academic Press. p.241-65.

Shorey, H.H. and I.M. Hall. 1963. Toxicity of chemical and microbial insecticides to pest and beneficial insects on poled tomatoes. J. Econ. Entomol. 56:813-17.

Smith, R.F. and K.S. Hagan. 1959. Integrated control programs in the future of biological control. J. Econ. Entomol. 52:1106-8.

Solomon, M.E. 1953. Insect population balance and chemical control of pests. Pest outbreaks induced by spraying. Chem. Ind. (London) 1953:1143-49.

Spencer, S.M. 1971. Fighting insects with insects. Nat. Wild. 9(1):48, 51.

Stanley, J.M. and C.B. Dominick. 1958. Response of tobacco and tomato hornworm moths to blacklight.' J. Econ. Entomol. 51:78-81.

Steinhaus, E.A. 1951. Possible use of *Bacillus thuringiensis* Berliner as an aid in the biological control of the alfalfa caterpillar. Hilgardia 20:359-81.

Steinhaus, E.A. 1959. On the improbability of *Bacillus thuringiensis* mutating to forms pathogenic to vertebrates. J. Econ. Entomol. 52: 506-8.

Stern, V.M. and R. van den Bosch. 1959. The integration of chemical and biological control in combatting the spotted alfalfa aphid, *Therioaphis maculata* (Buckton). Hilgardia 29:103-30.

Stern, V.M, R.F. Smith, R. van den Bosch and K.S. Hagen. 1959. The integrated control concept. Hilgardia 29:81-101.

Stern, V.M., I. M. Hall and G.D. Peterson. 1959. The utilization of *Bacillus thuringiensis* Berliner as a biotic insecticide to suppress the alfalfa caterpillar. J. Insect Pathol. 1:142-51.

Stern, V.M., R. van den Bosch and R.F. Leigh. 1964. Strip cutting of alfalfa for lygus bug control. Calif. Agr. 18(4):5-6.

Stern, V.M., R. van den Bosch, T.F. Leigh, O.D. Mc Cutcheon, W.R. Sallee, C.E. Houston, and M.J. Garber. 1967. "Lygus Control by Strip Cutting Alfalfa", Berkeley, Calif., University of Calif., Agr. Ext. (AXT-241).

Summers, F.M. and D.W. Price. 1964. Control of navel orangeworm. Calif. Agr. 18(12):14-16.

Tanada, Y. 1967. Microbial pesticides. In: Pest Control. Edited by W.W. Kilgore and R.L. Doutt, New York, Academic Press. p. 31-88.

van den Bosch, R. 1969. The toxicity problem comments by an applied insect ecologist. In: Chemical Fallout. Edited by M.W. Miller and G.G. Berg, Springfield, Ill., Thomas. p. 97-112.

van den Bosch, R. 1970. Pesticides: prescribing for the ecosystem. Environment 12:20-25.

van den Bosch, R. 1971a. Insecticides and the law. Hastings Law J. 22:615-28.

van den Bosch, R. 1971b. Statement in support of U.S. Senate Bill S1794 issued on September 30, 1971.

van den Bosch, R. Biological control. Ann. Rev. Ecol. Sys. 2:90-99 (In press).

van den Bosch, R., L.H. Dawson, V.D. Roth, and V.W. Brown. 1961. Promising new parasites of the Egyptian alfalfa weevil imported from southern Iran. Dibrachoides druso. Calif. Agr. 15(8):11.

van den Bosch, R., T.F. Leigh, D. Gonzalez and R.E. Stinner. 1969. Cage studies on predators of the bollworm in cotton. J. Econ. Entomol. 62:1486-89.

van den Bosch, R. and V.L. Marble. 1971. Egyptian alfalfa weevil ... the threat to California alfalfa. Calif. Agr. 25(5):3-4.

van den Bosch, R., T.F. Leigh, L.A. Falcon, V.M. Stern, D. Gonzalez and K.S. Hagan. 1971a. The developing program of integrated control of cotton pests in California. In: Biological Control. Edited by C.B. Huffaker, New York, Plenum Press. p. 377-94.

van den Bosch, R., G. Finley and C. Lagace. 1971b. Egyptian alfalfa weevil ... biological control possibilities. Calif. Agr. 25:6-7.

Varley, G.C. 1953. Insect population balance and chemical control of pests. Population theory and economic entomology. Chem. Ind. (London) 1953:1250.

Williams, Carroll M. 1967. Third-generation pesticides. Scientific American 217:13-17.

Wilson, M.C. and E.J. Armbrust. 1970. Approach to integrated control of the alfalfa weevil. J. Econ. Entomol. 63:554-57.

Wolfenbarger, D.A. 1965. Polyhedrosis-virus-surfactant and insecticide combinations, and Bacillus thuringiensis-surfactant combinations for cabbage looper control. J. Invert. Pathol. 7:33-38.

Woodall, K.L. and L.P. Ditman. 1967. Control of the cabbage looper and corn earworm with nuclear polyhedrosis viruses. J. Econ. Entomol. 60: 1558-61.

CHAPTER 8

LAWS AND REGULATIONS GOVERNING AGRICULTURAL PESTICIDE USE IN THE SAN JOAQUIN VALLEY

Within the past seventy years, California has developed a regulatory system for pesticides control that is far more detailed than systems of most other states. It is claimed that this system provides "the most comprehensive control over the sale and use of pesticides of anywhere in the world."[1] Although the system is a product of state law and is in part administered directly by the State Department of Agriculture, major responsibilities for administration and enforcement are delegated to county Agricultural Commissioners. The following four matters need to be considered pertaining to this regulatory system, particularly as it operates with regard to the sale and agricultural use of pesticides in the San Joaquin Valley: 1) the basic features, especially pesticides registration, permit control of the use of certain pesticides, and regulation of the pest-control business; 2) some effects of this system in preventing environmental damage; 3) suggested changes that might increase environmental protection; and 4) important litigation related to the use of agricultural pesticides.

I. Basic Features of the Agricultural Pesticide Regulatory System

A) Registration of Pesticides

For the manufacture or sale within California of any pesticide or "economic poison," the manufacturer, importer, or dealer must obtain a general license and an individual registration for each pesticide.[2] Registration is carried out on a product-by-product basis, as with federal registration of pesticides moving in interstate commerce.[3] Also as with federal law, the process of pesticide registration is closely tied to the establishment of a "tolerance" as required by California's "spray residue" law.[4] In most cases the state's tolerance is the same as that established by the federal government under the Food, Drug and Cosmetics Act.[5]

All California pesticide registrations must be renewed annually. In 1970, over 12,000 products were registered by the Director of Agriculture,[6] involving several hundred chemicals.[7] Fewer than half of these were products registered for agricultural use, the others being for home and garden use, vector control, or structural pest control.[8] In 1970, the annual license fee was greatly increased, to forty dollars per registered product, which is expected to lead to a significant decline in the number of registrations.[9]

The registration of pesticides includes approval of formulas and product labels, and in 1970 the Director of Agriculture was given authority to adopt a pesticide container code.[10] The registered label, in principle, controls the use that can be made of the product. It is unlawful in California to use pesticides in conflict with the registered label or with supplementary printed directions delivered with the pesticide, unless expressly authorized by the Director of Agriculture or the Agricultural Commissioner.[11] The use of registered pesticides is controlled further by the prohibition of "any substantial drift to other crops" and by the requirement in certain circumstances that the applicator of pesticides be in possession of a signed recommendation showing the dose rate, pest to be controlled, and other specified information pertaining to the application.[12] In 1969 the legislature issued a sweeping mandate to the Director of Agriculture with regard to pesticide registration: he is to "develop an orderly program for the continuous evaluation of all economic poisons actually registered" in order to "endeavor to eliminate from use in the state any economic poison which endangers the agricultural or non-agricultural environment, is not beneficial for the purposes for which it is sold, or is misrepresented."[13] Refusal of registration or cancellation of registration is expressly authorized for any pesticide:

a) "Which has demonstrated serious uncontrollable adverse effects either within or outside the agricultural environment."

b) "The use of which is of less public value or greater detriment to the environment than the benefit received by its use."

c) "For which there is a reasonably effective and practicable alternate material or procedure which is demonstrably less destructive to the environment."

d) "Which, when properly used, is detrimental to vegetation, except weeds, to domestic animals, or to the public health and safety."

e) "Which is of little or no value for the purpose for which it is intended."

f) "Concerning which any false or misleading statement is made or implied by the registrant or his agent, either verbally or in writing, or in the form of any advertising literature."[14]

Where the director has reason to believe that any of the above conditions apply to a pesticide and that its continued use "constitutes an immediate substantial danger to persons or to the environment," he is authorized, after notice to the registrant, to suspend the registration pending a hearing and final decision.[15]

B) Permit Control and Related Special Use Restrictions

In addition to the control over usage obtained through restrictions on the registered label, a special set of use controls applies to many pesticides in California. In two cases, those of Compound 1080 (sodium fluoroacetate) and thallium, the material can, be legislative directive, be used agriculturally only under the immediate supervision of a public official.[16] Other pesticides are subject, after investigation and hearing, to special regulation by the Director of Agriculture where he finds that they are "injurious to the environment, or to any person, animal or crop."[17] The Director of Agriculture has never published criteria for use in such investigations and hearings, but since 1950 the list of "injurious materials" has grown steadily. The list now includes some thirty-three chemicals: four arsenic compounds, thirteen organic phosphorus compounds, chloropicrin, a carbamate compound, and fourteen mercury compounds.[18] A separate portion of the injurious-materials lists, called "restricted materials," includes a number of chlorinated hydrocarbons such as DDT.[19]

Part of the special regualtion of injurious materials consists of a set of rules on the time and conditions of use. These rules require that the materials be "substantially confined" to the property to be treated, that neither the materials nor the emptied containers be dumped or left unattended where they may present a hazard, and that all persons known to be on property to be treated be warned, before application, of the nature of the material and the precautions to be observed.[20] They also require that some properties treated with certain organic phosphorus compounds be posted, that adequate protective devices be provided to employees engaged in handling or applying the materials, that notification be made to the owner of animals on property to be treated and in certain cases to beekeepers with bees on the property, or within one mile of it, and that the time be restricted within which workers are permitted to reenter the treated property.[21]

Another part of this special regulation consists of placing injurious materials under permit control.[22] This permit system is administered and enforced by the agricultural commissioners, leading to considerable variation in its operation throughout the eight counties of the San Joaquin Valley. One choice is whether to use a "job" or "seasonal" permit system or something in between. A permit system by the job requires that each particular application of a pesticide be the subject of an approved written application for a permit, although renewals are generally granted over the telephone. The material to be used, the pest to be controlled, and the location must be specified. A seasonal permit, on the other hand, gives "blanket" approval for one, many, or all injurious materials to be applied for various pest-control purposes throughout the agricultural season or the calendar year. When issued to a professional applicator, it may be good for all property within the county. A seasonal permit can be individualized to some degree by requiring that an individual "notice of intent" be filed with the agricultural commissioner within a specified time before each application. Typically, this period ranges from 12 to 48 hours.

A second choice of importance in operation of the permit system for injurious materials concerns permit conditions. Agricultural commissioners have the authority to attach conditions to injurious-materials permits,[23] and this may be done either generally or for particular permits granted. Such conditions can deal with a range of local considerations, such as particular drift problems posed by the local cropping pattern, meteorological conditions, and patterns of bee activity.

A third matter concerns the role of the grower, who is generally the owner or lessee of the property to be treated. State regulations provide that either the grower or a professional applicator, known as a pest-control operator, may apply for the permit, although in any case the applicator must be named.[24] Some counties in the San Joaquin Valley allow the professional applicator to take out the permit, while others require that this generally be done by the grower himself. The significance of these variations in operation of the injurious-materials permit system are considered below.

Subject to special regulation in addition to the injurious materials is a group of "injurious herbicides." Nine pesticides are on the injurious-herbicides list, which covers herbicides, such as 2,4-D and 2,4,5-T, which have been found by the Director of Agriculture to be "injurious to many plants and crops grown in various areas of the state."[25] Injurious herbicides are subject to special rules of use,[26] many of which are designed to cut down the chances of harmful drift to nearby susceptible crops. They are also subject in most cases to permit control by agricultural commissioners,[27] who administer and enforce the permit system for injurious herbicides much like that for injurious materials. Regulations of the Director of Agriculture, however, specify that, within certain designated "hazardous areas" (most of them within the eight-county San Joaquin Valley area), permits to use injurious herbicides within the period from March 15 to October 15 may not have a term of more than one week.[28]

In addition to the special controls provided for injurious materials and injurious herbicides, California law since 1969 has provided that the Director of Agriculture "shall prohibit or regulate the use of environmentally harmful material."[29] No definition of such material is provided, although "environment" is defined for these purposes as "the aggregate of all factors that influence the conditions of life in or about the state or within any portion thereof, and which are affected by the use of economic poisons or related materials within the state."[30] Several recent specific actions taken by the Director of Agriculture have been justified in terms of the need for environmental protection.[31]

C) Regulation of the Pest-Control Business

The past two years have seen a substantial broadening of the regulation of various phases of the pest-control business. Such regulation bears very directly on pesticide usage, in particular as it allows for a separate set of use rules for the professionals, who are estimated to sell nearly all and to apply more than half of the agricultural pesticides used in California.

Of the three distinct phases--recommendation, sale, and application-- within the pest-control business, application has historically been subject to the closest control. This phase, in fact, has historically been considered to constitute the "pest control business."[32] No one may engage for hire in the agricultural application of pesticides, i.e., act as a "pest control operator," without an agricultural pest-control license.[33] To obtain such a license, information must be submitted sufficient to satisfy the Director of Agriculture of the character, qualifications, responsibility, and good faith of the applicant.[34] The applicant must pass an examination to obtain the license, which may be limited to certain types of pest control: for example, weed control; control of pests other than weeds in commercial plantings; or defoliation.[35] This license is not required for a person who operates only in the vicinity of his own property "for the accommodation of his neighbors" and is not regularly engaged in the business of pest control. Even so, such persons must obtain a permit from the Director of Agriculture and, like agricultural pest-control licensees, register with a county agricultural commissioner.[36]

For air operations, pest-control operators may employ only pilots with a valid certificate or apprentice certificate of qualification issued by the Director of Agriculture.[37] By state law, employees who operate other pest-control equipment (ground spray rigs, for example) may be required by the county agricultural commissioner to qualify by examination or otherwise.[38] This authority has not been generally used, however. The equipment of pest-control operators is also subject to control,[39] and agricultural commissioners do inspect this equipment. They may order an immediate shutdown of any equipment operated by an incompetent person or otherwise operated in violation of state or local regulations.[40]

The pesticide use rules in force for licensed pest-control operators complement and often duplicate those outlined above for the use of injurious materials.[41] These rules govern all pesticides, "non-injurious" as well as "injurious," insofar as most of the rules on the time and conditions for use are concerned. Noninjurious materials used must also be whoen in the pesticide use reports required of pest-control operators; for nonprofessional applicators, use reports are required only for injurious materials subject to permit control.[42] Regulation of the agricultural pest-control business does not, however, require professional applicators to obtain a permit for the use of noninjurious materials.

In contrast to the regulation of professional agricultural pesticide applicators, which was begun by counties many decades ago, regulation of the recommendation and sales phases of the pest control business is very new in California. Since January 1, 1970, pesticide dealers--those "in the business of selling or retailing pesticides directly to users for an agricultural use"--must be licensed by the Director of Agriculture.[43] An applicant must satisfy the director of his knowledge of the laws and regulations governing the use and sale of pesticides, as well as his responsibility in carrying on the business of a pesticide dealer.[44] In addition, "agricultural pest control agents" must register with the agricultural commissioner in each county where they act in that capacity.[45] Such an agent is broadly defined to include three occupational categories (often overlapping): 1) those who, as an agent or employee of a pesticide dealer, distributor, or manufacturer, sell or offer for sale any pesticide for an agricultural use; 2) those who, as an agent or employee of a pesticide dealer, make any recommendation concerning the agricultural use of any method or device for the control of any agricultural pest; and 3) those who, in connection with a pest-control advisory service for hire (typically, the "independent consulting entomologist"), make any recommendation concerning the agricultural use or application of any pesticide.[46] "Agricultural use" is limited to commercial production, excluding home and garden use.[47] Legislation enacted very recently provides for state examination and licensing of these agricultural pest-control agents,[48] now to be known as "agricultural pest control advisers."

Unlawful activity by those under regulation is subject to administrative proceedings against their state license and/or county registration, as well as prosecution in the courts.[49] Enforcement is carried out primarily by agricultural inspectors on the staff of each county agricultural commissioner. The commissioners, deputy commissioners, and agricultural insepctors in the eight counties of the San Joaquin Valley in the period July 1, 1969, through June 30, 1970, devoted an estimated 3,964 man-days to pesticide inspection and enforcement work.[50] The work consisted primarily of individual review of use reports that pest-control operators must file, field inspection of pest-control equipment and operations, audits of dealer and operator records, investigation of complaints, and issuance of warning notices. All use reports, after such review, are now forwarded to Sacramento for review by a computer. This review may indicate a possible violation in a pesticide application (for example, a violation of dose limitations established by the registered label), leading to a further check in the field.

D) Other Relevant Laws and Regulations

Several other state agencies also have authority that does or could significantly govern the sale and use of agricultural pesticides. Some of this authority relates primarily to human health and safety, in particular the health and safety of those exposed occupationally to agricultural pesticides. For example, the Division of Industrial Safety (a part of the State Department of Industrial Relations) has authority for the enforcement of Safety Orders for Agricultural Operations.[51] These orders include provisions on the operation and decontamination of equipment used in application work and they require medical supervision for all employees regularly occupied in the formulation or application of organic phosphate injurious materials.[52] The reduction of occupational hazards from agricultural pesticides is also the subject of study and, sometimes, enforcement activity by the State Department of Public Health (through its Bureau of Occupational Health and Epidemiology) and by county departments of health.

Of greater importance to environmental protection, however, is the authority of those concerned with resource protection. The State Water Resources Control Board and regional water quality control boards administer and enforce the State's Porter-Cologne Water Quality Control Act and related sections of the water code.[53] Most of the eight-county San Joaquin Valley lies within the Central Valley region, for which an Interim Water Quality Management Plan was promulgated in June 1971.[54] As part of this interim plan, the Central Valley Regional Water Quality Board established "water quality objectives" providing that pesticides in most of the region's surface water bodies shall not reach concentrations "found to be deleterious to fish or wildlife," nor shall there be an "increase in pesticide concentrations over background levels in indigenous aquatic life."[55] Further, specific limitations on pesticide concentrations were established for particular bodies of water, e.g., 0.6 μg/liter in the Sacramento-San Joaquin Delta, as determined by the summation of individual concentrations.[56] Such water-quality objectives, however, do not necessarily lead to the establishment of waste-discharge requirements. It is this latter step, which normally provides effluent standards as well as some receiving-water standards, that lays the basis for enforcement against particular water users under the control scheme provided by Porter-Cologne. During the past two decades regional water-quality control boards establishing waste-discharge requirements in California have concentrated on municipal and industrial dischargers, in most instances leaving agricultural dischargers without significant regulation. Within the Central Valley Region, for example, no waste-discharge requirements have been set for return irrigation waters, as to either pesticide content or other parameters. In general, the hazard from pesticide residues in agricultural waste waters seems to have been judged to be low. In February 1971, however, the State Water Resources Control Board held two days of hearings on pesticides in the environment,[57] and an Agricultural Advisory Committee to the Board was recently appointed to study methods to control agricultural wastes that may harm water quality.[58] Thus, some general changes may be in the offing in water-quality policy and regional board practice with regard to agricultural waste waters.

Water-quality officials in the San Joaquin Valley have thus not yet generally regulated pesticide levels in agricultural effluent, although action has been taken to avoid the possibility of degradation of ground and surface waters by pesticide containers disposed of in dumps. Regional water quality control boards classify dump sites in order to protect water bodies, and the Central Valley Regional Water Quality Control Board, by resolution, determined in 1969 that toxic chemicals--including agricultural pesticides and their containers--can be disposed of on land only at Class I disposal sites.[59] These are sites "located on formations through which no appreciable seepage to usable waters can occur, or underlain by isolated bodies of unusable ground water, and which are protected from flooding and surface runoff and where waste materials and all internal surface drainage can be restricted to the site.[60] This broad policy determination was reached after consultation with the State Department of Public Health, but the San Joaquin Valley's total lack of approved and publicly-controlled Class I sites is a significant problem, considered further below.

The activities and attitudes of two other state agencies for the protection of resources also bear on the sale and use of agricultural pesticides in the San Joaquin Valley. The Department of Fish and Game, which has wardens and deputies in the field throughout the valley, has for many years been concerned about the impact of pesticides on fish and wildlife. Section 5650 of the California Fish and Game Code provides authority for enforcement activity of extraordinary scope, for it makes it unlawful to deposit in, permit to pass into, or place where it can pass into the waters of the state, any substance or material that is "deleterious to fish, plant life, or bird life."[61] Thus, in the case of specific fish kills (for example, from direct application of pesticides to water bodies), the Department of Fish and Game has engaged in its own direct enforcement activity. It has also worked closely with the regional water quality control boards, in accordance with the mandate of Section 5651 of the Fish and Game Code that, in cases of continuing and chronic pollution, Fish and Game shall "act through" the regional board "in obtaining correction in accordance with any laws administered by such board for control of practices for sewage and industrial waste disposal."[62]

In addition to the State Water Resources Control Board, regional water quality control boards, and the Department of Fish and Game, California has a State Air Resources Board "for administration, research, establishment of standards, and the coordination of air conservation activities carried on within the state."[63] This board establishes air basin boundaries within the state, sets quality standards for ambient air in each basin, and has various powers in the control of vehicular emissions.[64] The initial responsibility for control of injurious air contaminants from nonvehicular sources, which appears to be the category into which most pesticide emissions would fall, lies with county or regional air-pollution control districts. These districts enforce a general provision of the Health and Safety Code that prohibits the discharge of such quantities of air contaminants as to "cause injury, detriment, nuisance or annoyance to any considerable number of persons or to the public or which endanger the comfort, repose, health or safety of any such persons or the public or which cause or have a natural tendency to cause injury or damage to business or property."[65]

They also enforce more specific restrictions, certain of which are expressly made applicable to agricultural operations, including the operation of aircraft "to distribute seed, fertilizer, insecticides, or other agricultural aids over lands devoted to the growing of crops or raising of fowls or animals."[66] However, despite the various possibilities for regulatory activity regarding pesticides that state law gives to the State Air Resources Board and the various air-pollution control districts, no significant action has been taken. Existing standards for ambient air quality make no reference to pesticides, and staff activity has been limited to some sporadic sampling of pesticide residues in the atmosphere. Air-quality officials in California presently give priority to urban air-pollution problems, such as smog; concentrate their rural air-quality efforts on problems of burning; and consider that any hazards from agricultural pesticides are best managed by other agencies of the state.

Aside from the specific authority given particular state or local agencies to regulate either input (application) or output (waste) aspects of agricultural pesticide sale and use, state law now has general environmental provisions that may affect these activities. The California Environmental Quality Act of 1970, similar in purpose and content to the federal National Environmental Protection Act of 1969,[67] requires, for example, that both state and local agencies prepare environmental-impact reports for their proposed projects that could have a "significant effect" on the state's environment.[68] These various forms of present or potential public regulation of pesticide activity are supplemented by a form of "private regulation" through the use of restrictive contract provisions. These appear frequently in contracts between growers and canneries, which seek to avoid over-tolerance pesticide residues on food products. Pesticides clauses have recently also been inserted in contracts between growers and the United Farmworkers Organizing Committee, which seeks to minimize pesticide hazards to union members.

II. Agricultural Pesticide Regulation and Prevention of Environmental Damage

No complete assessment is yet possible of the effects of California's present agricultural pesticide regulatory system in preventing environmental damage, for far too little is now known about the nature and extent of environmental damage brought about by agricultural pesticides, and about the manner in which various laws and regulations have actually changed human behavior. As an alternative to such an assessment, this section considers certain administrative and structural aspects of the present regulatory system, and their bearing on environmental protection in the San Joaquin Valley.[69]

A) Registration of Pesticides

In its 1970 annual report to the California legislature on environmentally harmful pesticides,[70] the Department of Agriculture placed considerable emphasis on its use of the pesticide registration system to eliminate environmentally harmful materials. It noted continued progress in the phasing-out of DDT and DDD, which have been removed from 67 crop and animal uses, plus home and garden uses.[71] These registration cancellations have led to a continued sharp decrease in actual use of DDT and DDD. The use of DDT in California in 1970 and 1971 is shown in the following table, based on summaries of state reports on pesticide use.[72]

Use	Applications	Acres[a]	Pounds
DDT--1970, first half	3,313	168,794.84	281,989.88
1970, full year	8,284	643,899.13	1,164,699.91
1971, first half	320	8,811.71	13,954.38

[a] Nonagricultural uses such as structural and vector control are excluded.

A number of registrations of products containing mercury were also canceled in 1970,[73] and the cancellation of most registrations for mercury compounds for seed treatment has now been approved by the Director of Agriculture.[74] These DDT/DDD and mercury cancellations, of course, have coincided with federal action on these materials and with widespread public concern over their effects in the environment.

In addition, the Department of Agriculture has reported registration cancellations of 91 different pesticides on farm crops, and "new restrictions" on another 120 pesticides, many in the chlorinated hydrocarbon group.[75] Since pesticide registration is on a product-by-product basis, action on a single chemical may mean many cancellations. In any case, many of these cancellations were for reasons other than environmental protection, and at least 10,000 registrations remain in force. Further, in some cases the canceled materials "have never been used in California or they have limited uses and substitute materials are available."[76] In carrying out its cancellations and restrictions for environmental or other reasons, the Department of Agriculture has had the services of a Pesticide Advisory Committee composed of experts,[77] while the staff of the department itself has only three permanent professional registration specialists. With the limited resources now devoted to the registration process, [78] attention seems to be centered on materials that "come into the limelight" for one reason or another, rather than on the "orderly program for the continuous evaluation of all economic poisons actually registered," that the legislature mandated in 1969.[79] In view of the historic (and quite possibly inevitable) extensive reliance on federal registrations by those in state pesticide-registration work, as well as the prospect that the federal government may require federal registrations for pesticides moving only in intrastate commerce,[80] it may be somewhat unrealistic to expect the State Department of

Agriculture to carry out independently its own continuous and comprehensive environmental evaluation of all registered pesticides.

Aside from the questions of which pesticides should receive a state registration and how such decisions should be made, important questions arise as to how the registered label should be employed to control use. Both those in regulatory positions and those in one phase or another of the agricultural pest-control business throughout the San Joaquin Valley are intensely interested in the need for label standardization, an objective that suggests it might be necessary to allow less diversity in the production of agricultural pesticides. Minor variations in label requirements (e.g., maximum dose) for products that are fundamentally the same chemical material make field monitoring and enforcement of label requirements more complex than perhaps need be the case. At the same time that there may be a need for standardization, however, a number of local regulatory officials point out that proper control of pesticide use might require much more information than most labels now provide. They assert, for example, that more information is needed in many cases on the use of a material in relation to local meteorological conditions, bee behavior patterns, and worker reentry into the field.

B) Permit Control and Related Special Use Restrictions

Although in principle the registration process itself provides specific control over the use of agricultural pesticides, since it is unlawful to use the registered product contrary to the label or related directions without special authorization, label provisions cannot deal with the multitude of local problems that depend in large measure on local crop-production patterns and practices. They can be no more than a direction from afar to the actual user--and the user may or may not read the label, may or may not understand and respect the label's directions for use, and may or may not anticipate a significant risk of detection should the use directions be violated. For more than two decades the permit control system for injurious materials and injurious herbicides has therefore been the vehicle in California for specific, direct contact between the government and citizen as to pesticide usage. In the spring of 1971, when the Congress had under consideration the first version of an administration bill to provide federal "environmental" pesticide control,[81] an official communication to an official of the Council on Environmental Quality from a California Department of Agriculture specialist in agricultural chemicals suggested five situations in which California's permit system has "reduced" pesticide problems:[82]

1) In the early 1960's, DDT was drifting onto alfalfa hay that was later fed to dairy cows, and illegal DDT residues resulted in milk supplies. In 1963 DDT was classified as an injurious material, and county agricultural commissioners, in granting required permits, imposed restrictions prohibiting its use near alfalfa. "We found that with the control of DDT by permit system there were substantially fewer interceptions of hay with illegal residues and fewer problems with DDT residues in milk and dairy products. While certain other factors were also operating to alleviate the drift residue problem, we believe the requirement of a permit for use was by far the most significant."[83]

2) In 1946 and 1947, 2,4-D was first widely used on grain crops as a selective herbicide. Susceptible crops such as grapes and cotton were injured. The material was classified as an injurious herbicide, and the highly volatile esters were prohibited in most areas of the state. State regulations required that permits issued by county agricultural commissioners incorporate various restrictions on 2,4-D applications. These covered minimum distances from susceptible crops, specifications of nozzle size, pressure, nozzle orientation on the spray boom, and similar items. "While these controls did not eliminate every problem with 2,4-D, they worked effectively to allow increasingly extensive use of 2,4-D and other phenoxy type herbicides with a minimum of difficulties."[84]

3) In the early 1950's chloropicrin ("tear gas") began to be widely used as a soil fumigant. In populated areas it sometimes drifted into houses, requiring evacuation of the residents. Chloropicrin was then placed on the injurious-materials list, permits were made mandatory for most applications in the three counties where problems had arisen, and certain specific use restrictions were imposed by state regulation. For example, in certain situations in which this material is used in the specified counties, the area must be covered with a gas-confining covering immediately after

treatment. "There have been no further problems in these counties in spite of continued and probably increased use of the fumigants."[85]

4) In 1947 parathion came into widespread use in California, and in the next several years there were numerous illnesses and some fatalities from parathion poisoning. In 1950 parathion was classified as an injurious material. "While the usage increased greatly in the state in succeeding years we substantially were able to reduce accidental injuries. The permit requirement probably can not be given sole credit however, because there was a strong program launched to educate users better about the hazards of parathion."[86]

5) Before 1961 sodium arsenite caused an average of four or five deaths a year in California. Many of these fatalities occurred where the material had been purchased for home and garden use. In 1961 sodium arsenite was classified as an injurious material, and a permit was required for use. "This had the practical effect of causing the product to disappear from retail outlets because householders did not choose to go through the procedure of getting a permit to use it. In any event the number of fatalities attributed to this substance was promptly reduced to zero."[87]

These illustrations of operation of the permit system seem to justify three general conclusions:

First, major initiatives for action have generally come from the state rather than from the various counties. Under California law, only the state (through the Director of Agriculture) can classify a pesticide as an injurious material or injurious herbicide, but counties could do much to meet particular problems--through county ordinance (placing a "noninjurious" material under direct regulation) or through detailed permit conditions established by the counties once the state has provided the basis for permit control. The counties in the San Joaquin Valley have made scant use of either of these possibilities, although individual commissioners "behind-the-scenes" may have urged the state to act. County initiatives are not impossible in California, for one county outside the San Joaquin Valley (Imperial County, in the desert agricultural area in the southeastern portion of the state) has for many years, by county ordinance, required a permit for all noninjurious materials (i.e., all materials not already under state regulation) and has also made considerable use of its own permit conditions to control both injurious and noninjurious materials. With the sharp increase in use of agricultural pesticides beginning just after World War II, however, the counties in California have generally left the major initiatives to the state. Indeed, it was the 2,4-D drift problems noted above that led, in 1950, to the state's taking major aspects of the present regulatory system over from the counties.

Second, as a general proposition, classification as an injurious material or injurious herbicide, followed by special use restrictions and permit control, has come after a problem has arisen. This sequence is clearly illustrated by each of the five examples of operation of the California permit system noted above. Even today organic phosphates with an established toxicity comparable to some of those on the injurious-materials list have not been so classified and hence are not subject to the extra control the permit system provides.[88]

Third, environmental considerations have been secondary in using the permit system to bring more precise control of pesticide use. More typically regulation has been undertaken because of pressure from a segment of the agricultural world aroused over damage to crops or food products from pesticide applications. Thus, the alfalfa hay growers and, particularly, the dairy interests of the state pressured for the DDT restriction of 1963, although the environment doubtless benefited incidentally through generally reduced levels of DDT use. Similarly, 2,4-D was brought under special regulation because of the concern of growers of susceptible crops. Where the motive for control has not been the protection of grower interests, there has been concern over occupational health (parathion), public health (sodium arsenite) or public relations (chloropicrin). One attempt in the San Joaquin Valley has been made to use the permit system for environmental purposes when the pesticide Azodrin caused wildlife losses. That attempt is discussed below.

As more pesticides become subject to permit control, questions about the mechanics of the system become increasingly important. When permit lists are short or agricultural activity in a county is relatively limited, each pesticide application can easily receive individual review by regulatory officials. Madera County, in the San Joaquin Valley, operates its permit system largely on such a job basis. In contrast, the larger counties, with intensive agricultural activity, may have hundreds of applications a week during the busy season. One consequence can then be a mechanical "paperwork" system: clerical personnel handle the applications that flood in, virtually all are approved, and inspection personnel spend more time in the office than in the field. A different consequence can be that permits are required on a job basis only for infrequently used or specially hazardous materials. This means there is no advance review of most applications at all be regulatory officials, nor is there even any systematic way for knowing in advance what materials are being used where for what purpose. This latter problem may not be serious, insofar as field observation of application activity is concerned, particularly where district agricultural inspectors within a county have detailed information about the application equipment in use. But lack of opportunity for advance review may abort any problem-preventive function of a permit system, besides destroying any potential that the permit system has for reducing marginally necessary (or even entirely unnecessary) applications that contribute to environmental degradation.

Essentially, the problem in administering a large pesticide permit system is to balance possible benefits in changed human behavior against costs of increased paperwork and, possibly, economic losses from delays caused by a cumbersome system. Fresno County recently changed its permit system in an interesting fashion: instead of the applicators' notice of intent to make application going through the Department of Agriculture (as some other counties have required, with the inevitable tie-up of county personnel in receiving and handling notices of intent), the notice is (in most cases) simply placed, shortly prior to the expected time of application, in a "drop box" in the district where the application is to be made. The district inspector can pick it up, review it quickly and systematically, and selectively follow-up on it as necessary. Under this method of administering the permit system, a number of projected pesticide applications have been denied by district inspectors. The system reduces paperwork while providing advance review, which seems essential if particularly hazardous or unnecessary applications are to be eliminated at the local level.

C) Regulation of the Pest-Control Business

It has been fashionable for some years in certain entomological circles to talk of the need to use agricultural pesticides on a "prescription-only" basis. The parallel with the use of drugs for human medication is compelling and places the two situations in striking contrast. In human medication a certain drug is prescribed by a highly trained and state-licensed doctor, ideally on the basis of careful consideration of need and relative net costs and benefits to the patient. In agricultural pest control, those who recommend a particular toxic chemical upon some kind of "diagnosis" may not have extensive training in either entomology or, often, any agricultural science, and in the past they have not been subject to any kind of occupational regulation by the state. Instead, the occupational regulation has been imposed on the applicators of agricultural pesticides, whose position is comparable to that of the pharmacist.

Some steps are now being taken to correct this situation in California. It will require a major occupational upgrading and restructuring. In the human-medication area, the potential individual cost to a patient from a faulty recommendation seems to have been enough to bring close regulation by the state. Failure to provide comparable regulation of those who recommend agricultural pesticides has perhaps reflected a belief that any cost of faulty recommendations will simply be economic, borne by the grower in the form of wasted materials or crop losses from ineffective pest control. Closer regulation of application work may have reflected a recognition that faulty application can harm not only the grower but his neighbor, damaged by drift. In any event, the possibility of major social costs has not been acknowledged by the occupational regulatory system--particularly long-term public and occupational health hazards and short-term or long-term environmental damage.

Thus, regulatory control of the use of registered pesticides in California has concentrated exclusively on applicators until very recently. With regard to *air* applications, control has been relatively strict over both pilots and the pest-control operator licensees. But for *ground* applications, systematic direct action has been lacking to ensure that actual operators of ground equipment are fit for the work. Agricultural commissioners have the power to examine the qualifications of operators of ground rigs, but they have not ordinarily done so even though it seems important from many points of view, including environmental protection and occupational health and safety.

Furthermore, with regard to the state licensees/county registratnts themselves, in most cases a violation results only in a "notice of warning." Such notice *may* lead to an informal "office" hearing and then a formal hearing before an examiner from the State's Office of Administrative Procedure, and finally to suspension or revocation of the operator's license. The 760 warning notices issued by county officials *throughout* the state for the period July 1, 1969, through June 30, 1970, in connection with the agricultural pest-control business led to only 88 office hearings.[89] These resulted in 56 suspensions or revocations of agricultural pest-control authorizations.[90] Despite the fact that roughly 45% of California's agricultural production is from the San Joaquin Valley, of these 760 warning notices only 157 were issued by inspectors in the eight counties of the valley--and 107 of these were in Merced County.[91]

The possibility remains, of course, of prosecution for a misdemeanor. Such prosecutions are rare. Department of Agriculture figures show only two such prosecutions for the entire state in the period July 1, 1969, through June 30, 1970.[92]

D) Other Relevant Laws and Regulations

As pointed out, several state agencies other than the Department of Agriculture have responsibilities bearing on regulation of the sale and agricultural use of pesticides in the San Joaquin Valley. The effects of the activities of these other agencies in working with the Department of Agriculture can be evaluated best by considering two particular problems that have arisen in recent years. One such problem is now largely resolved: adverse effects on wildlife from use of the organic phosphate Azodrin. The second remains unresolved: potential harm to water quality from disposal of used pesticide containers.

1) Azodrin and wildlife: In June 1965 the California Department of Agriculture registered Azodrin for the control of certain insect pests in cotton fields. This pesticide was used in limited quantities in the San Joaquin Valley in the 1965 cotton season, although wildlife losses associated with its use were already known by the Department of Fish and Game.[93] Such losses included pheasant, doves, quail, jackrabbits, horned larks, meadowlarks, blackbirds, killdeer, and sparrows.[94] Field studies of Azodrin-wildlife relationships initially emphasized dermal toxicity (e.g., as indicated by spraying pheasant and quail in

experimental situations). That approach may explain the preliminary (1966) conclusion of the Department of Fish and Game that Azodrin was "not as hazardous to wildlife as certain other organic phosphate insecticides in common use."[95] Even so, in terms of oral toxicity it was already recognized that "Azodrin is one of the most toxic of all agricultural chemicals used in California to birds."[96]

A serious production setback in 1966 at the Shell Chemical Company, manufacturer of Azodrin, made very little of the material available during that cotton season. In 1967, however, the material was used very widely, particularly for control of Lygus bug on cotton. The chemical received enormous publicity, possibly the largest promotion in California pesticide history.[97] Azodrin was promoted as a major breakthrough in cotton pest control, and the manufacturer and distributors suggested its use of a prophylactic fixed-schedule basis.[98] By the end of 1967, applications of the material in the valley apparently exceeded 1,000,000 acres.[99]

Throughout that year, the Department of Fish and Game carried out intensive field investigations of the effects of this pesticide on wildlife. Departmental personnel expressed their serious concern to personnel of both the Department of Agriculture and the manufacturer, and the latter agreed to inform users that Azodrin should not be applied to cotton fields under irrigation. This agreement was based on "circumstantial evidence that Azodrin-contaminated water might be implicated in wildlife losses."[100]

Those with wildlife management responsibilities continued surveillance of Azodrin use on cotton fields in the San Joaquin Valley throughout 1968. By that time, Fish and Game officials, from field tests conducted by the Shell Chemical Company, felt that "the greatest hazard to birds exists in treated cotton fields where standing water and excessive weed growth are present."[101] Such conditions, they reported, "are more apt to occur on small acreages of cotton in diversified farming areas,"[102] i.e., on the east side of the valley.

Although the pesticide was still not under any form of special regulation, usage was lower than in 1967. Local observers attributed the decline to the high costs of regular, repeated applications, combined with doubts about the efficacy of the material. Such observers noted in particular that Azodrin was nonselective, harming beneficial insects as well as pests.[103] A series of regulatory measures designed to reduce harm to wildlife from Azodrin were agreed on in 1969 after extensive negotiations between the Department of Agriculture, the Department of Fish and Game, and the manufacturer. By May 1969 the concerned parties agreed that Azodrin would be placed on the injurious-materials list; that a permit would be required for any application within the state; that job permits would be required after the end of July in certain "special areas" (basically, the east side of the valley) and granted only after the agricultural commissioner or his representative insepcted the property to be treated, consulted with regional personnel of Fish and Game, and determined that the pesticide could be used on the particular property without significant loss to wildlife; that it would be emphasized to all persons using Azodrin that irrigation practices should be managed so as to minimize the opportunity for contamination of water with the pesticide; and that Azodrin use permits would be issued 30 days or more in advance of the anticipated time of use, unless the commissioner, after consultation with wildlife management personnel, determined that this should not be done.[104]

On the basis of this agreement, in mid-1968 the Department of Agriculture proceeded with a hearing that led, on July 18, 1969, to the addition of Azodrin to the injurious-materials list.[105] To prevent the use of Azodrin in areas frequented by significant bird populations, use restrictions were promulgated on a county-by-county basis. These became effective on August 1, 1969, with job permits required in these special bird-protection areas and close consultation required between county agricultural commissioners and regional personnel of Fish and Game. Criteria for denial of permits were keyed to weed conditions (denial for "excessively weedy" fields attractive to birds for feeding), drainage conditions (denial for poorly drained fields attractive to birds as sources of water), bird habitat (denial for fields with high resident bird populations or adjoined by such), and surrounding crops (denial for small fields surrounded by diverse crops attractive to wildlife or adjoined by such).[106]

The final agreement was developed from years of negotiation between the concerned agencies and the pesticide manufacturer and yet it appears that the consultative system agreed upon entirely collapsed in the majority of San Joaquin Valley counties. An example is Fresno County, the valley's leader in production. The agreed regulations and procedures provided that Azodrin use permits in Fresno County would be issued only on an individual-field one-application basis, and that all fields would have to meet criteria of the Department of Fish and Game before a permit would be issued by the agricultural commissioner. The collapse in interagency consultation was recited in an internal report made by personnel in Fish and Game's regional office:

> "Beginning about the first of August, 1969 the Fresno County Agricultural Commissioner's office began a program of periodically notifying the Region 4 [Fresno] office of all requests for permits to apply Azodrin. The first seven requests for permits, covering 16 separate fields, were field checked by Department personnel for compliance with established criteria. Our personnel recommended against the issuance of all seven permits. After that, permits were issued by the Agricultural Commissioner without our prior recommendation. During the first four weeks of this program, there were 520 requests received for permits to apply Azodrin in Fresno County. Of these, 474 were issued permits, 30 were refused, and 16 were requested to alter operations before a permit could be issued."[107]

Although other San Joaquin Valley counties did not experience as heavy Azodrin use in 1969 as did Fresno County, and anticipated close coordination and consultation, often on a field-by-field basis, appears not to have occurred anywhere. Wherever Azodrin use was low that year, as in Tulare County, the reason seems to be that personnel within the agricultural commissioner's office simply decided to permit Azodrin only in extraordinary circumstances. Control was tightest in the special bird-protection areas, mostly on the east side of the valley, where the hazard to wildlife was supposedly greatest because of the dominance of small and diversified acreage. Remarkably, the west side seems better known for pheasant hunting, and it also has enormous cotton acreages, with a concomitant enormous potential for Azodrin sales. In any event, the emphasis in the criteria favored east-side protection and seems to have left Azodrin sales on the west side comparatively unaffected throughout the 1969 season.

Whatever the reason, by 1970 it was clear that the Azodrin problem would not be solved by local consultation between agricultural and wildlife management personnel in applying the agreed criteria. Whether no cotton field would qualify for Azodrin if the criteria were strictly applied, whether local officials simply cound not agree on what constitutes a "weedy" cotton field, whether there was bias or intransigence on one side or the other, some other solution had to be found. It was found at the state level, in modification of the registration for Azodrin: a prohibition of its use on cotton under any circumstances after July 15 each year.[108] Controversy has been minimal since this change, which came five years after the initial warnings about Azodrin and after its use had already peaked and begun a sharp decline for reasons largely unrelated to wildlife protection. This problem is thus, in a sense, resolved.

This sketch of regulatory responses to the Azodrin-wildlife problem is provided in some detail primarily as a major instance in which the regulatory efforts of a resource-oriented agency have collided with the reality that the significant powers in pesticide control are vested by state law in a production-oriented agency. The events in the valley seem to mirror patterns in pesticide regulation at the national level: allegations of environmental harm; responsibility given to the manufacturer for investigating the allegations; continued unchecked use for several years while research continues; a frequent inability of agricultural-production-oriented and resource-protection-oriented officials to function together; and, finally in this case, effective regulation only after the problem had largely disappeared for other reasons.

2) Ground disposal of used pesticide containers: The disposal of used agricultural pesticide containers is a second problem area that has tested the capacity to work together effectively of agricultural regulatory officials and regulatory officials with public-health or resource-protection responsibilities. Although certain methods of disposal, such as incineration, may create problems in air quality, attention here is centered on the potential for degradation of water quality associated with ground disposal of emptied pesticide containers. As noted above, regional water quality control boards in California have the authority to classify ground-disposal sites (such as dumps) to protect water quality, and the Central Valley Regional Water Quality Control Board, after consultation with the State Department of Public Health, resovled in 1969 that used pesticide containers are to be disposed of only at Class I dump sites (so situated that no liquid drainage can reach ground waters later). Further, waste-discharge requirements have been set prohibiting many dump sites throughout the valley from accepting such containers without special authorization.

Although approved and publicly-controlled Class I dump sites are readily available in many parts of California, at the end of 1970 there was not one within the entire San Joaquin Valley. Consequently, by early 1971 a massive backlog of emptied pesticide containers had built up in several of the San Joaquin Valley counties. Early in 1971 state and industry personnel determined that a "one-time" special "clean-up" program of used pesticide containers should be undertaken.[109] As with the Azodrin-wildlife "cooperative" project of earlier years, the operation and consequences of this project illustrate the potential for effective cooperation between industry, local regulatory officials, and state regulatory officials in solving pesticide-created problems that have environmental aspects. In this case, of course, the situation is further complicated by the fact that emptied pesticide containers can be a hazard to public health and safety as well as to soil and water quality.

The clean-up program was stimulated by complaints from agricultural commissioners about the growing backlog of used containers being stored, properly or improperly, on ranches and applicators' lots throughout the state. Operation of the program itself was planned largely by an interagency committee of state and industry personnel. The plan adopted was that, for one time only, accumulated containers could be disposed of at selected Class II sites, but only after being rinsed out to reduce the amount of concentrated pesticide in them. Rinsing facilities were to be provided by local pesticide dealers and pest-control operators, who would work under the general supervision of the county agricultural commissioners. This plan was approved by representatives of the Department of Public Health, the Department of Water Resources, and the State Water Resources Control Board, as well as the Director of Agriculture's Pesticide Advisory Committee. Implementation was scheduled for early March 1971, so that the program could be completed before the year's heavy spraying season began.

Thousands of used containers were in fact collected, rinsed, and disposed of at various dump sites throughout the state. Participating counties reported that some 28,000 containers had been handled, with no accidents or injuries reported. A press release issued by the Department of Agriculture at the end of March said that the program was "a great step forward," which "showed agriculture's concern about environmental problems, and its willingness to clean its own house ... Cleaning and disposal of empty pesticide containers is an immediate and short-range solution to a serious problem, [although the] long-range solution has not yet been found."[110] One finds progressively less enthusiasm, however, as one goes down the line from the top of the state hierarchy, through intermediate-level state personnel who coordinated the program, to local personnel who implemented it in the San Joaquin Valley counties. The state coordinator of the program publicly stated several months later that the program was "a success,"[111] but as much in terms of gaining knowledge of and attention for critical problem spots as in terms of actual disposal of used containers or the development of procedures that could be followed again in the future. Many of the agricultural commissioners themselves, in contrast, were sharply critical. Certain counties with serious container-disposal problems refused to participate at all in the program. The counties in the valley that did participate found that industry cooperation was minimal in many cases, although industry support had been promised "at the top" by the Executive Director for the Western Agricultural Chemicals Association. Sites for collection and washing were not freely provided by many in the industry, approval of procedures for disposal of the waste water from the rinsing operations was in some cases difficult to obtain, and the commissioners, with no special funds made available, found themselves charged with supervisorial and transport responsibilities. The general views of agricultural officials interviewed in the San Joaquin Valley can be summarized by a few comments made by agricultural commissioners in response to a questionnaire of the Department of Agriculture:[112]

> a) "Statewide news releases were premature. Agency and association heads made certain comments without first determining whether local representatives were in agreement."

b) "Before offering the help of the commissioner, the Director should thoroughly discuss the program with them. Extremely poor communication between industry and industry representatives."

c) "There is general lack of interest..."

All concerned with the problem of used pesticide containers in California recognize that no long-term solution has been found, although opinions differ as to the seriousness of the problem. As pest-control operators point out, they apply millions of pounds of pesticides directly to the soil each year, generally without restriction as to proximity to the water table, yet, in the interests of water quality, they face severe restrictions in disposal of emptied containers holding only a tiny fraction of the total amount of chemical used. On the other hand, water-quality regulatory officials emphasize that the materials often reach dumps in concentrated rather than diluted form; that present data showing that pesticides travel slowly in the soil and that residue levels are low in groundwater supplies do not assure against a future "breakthrough" of accumulated residues to groundwater supplies; and that any such breakthrough and the resultant pollution would quite possibly be irremediable. Study is under way of four alternative management systems for used containers, suggested by the Chief of the Bureau of Vector Control and Solid Waste Management in the Department of Public Health:[113]

a) Disposal of all containers in Class I sites: this principle is the present policy, at least in regions where adopted by the regional water quality control board. New Class I sites would have to be developed on a regional basis.

b) Disposal of rinsed containers in Class II sites: this would require that approved procedures be developed to be sure the containers are in fact decontaminated before ground disposal.

c) Disposal of unrinsed containers in Class II sites: this would reverse current policy simply because of the implementation difficulties encountered. As stated by the Department of Public Health official mentioned above, many "individuals familiar with the problem of disposing [sic] pesticide containers believe that current requirements are too restricitve. It has been indicated that recognition has not been given to the possible capability of the soil to sequester these materials through chemical, biological or physical reactions, and therefore, if true, Class I disposal site conditions may not be necessary." Variations might be appropriate, depending upon geological conditions, rainfall patterns, and similar factors at particular Class II sites.

d) Reuse of containers: this solution, involving some kind of "recycling," is favored (with recycling by return of the containers to the seller) by three-quarters of the agricultural commissioners who participated in the March 1971 clean-up. Because most pesticide containers are damaged in one way or another in use, they would have to be reconditioned to meet state and federal standards. Commercial reconditioning in California has been very limited so far, and done only on the larger containers (30 or 55 gallons). Many local officials appear to support the stated position of the former Executive Director of the Central Valley Regional Water Control Board that "the responsibility for disposing of these used containers should be placed on the architects of the problem, i.e. the companies who produce pesticides and who exercise control over the selec-

> tion of their product's shipping envelope. The responsibility is properly theirs because the real cost of using a particular container is the sum of the costs of production and of disposal, and optimization of these costs requires that the cardinal decisions be made by one party."

California's experience in the March 1971 "one-time" pesticide container clean-up, the legal and administrative measures creating the backlog that required the clean-up, and present efforts to resolve the existing problem (with its various environmental, public-health, and economic ramifications) can be summarized as follows. The extensive prior consultation and planning proved to be too little for the multitude of interests and entities involved. Policy, made "at the top," was perhaps admirably and properly far-sighted in seeking maximum protection of the public interest by limiting all pesticide containers to the safest of disposal sites, but it failed to take adequate account of the practical difficulties of implementation. Those at the county level with implementation responsibilities, both for regulation of dump sites and pesticide use generally and for the one-shot clean-up program, viewed the program largely as one thrust upon them from the top. They were given the field administrative responsibility without extra resources to carry out this responsibility. The work load, further, was quite possibly unnecessarily high since all pesticide containers were treated alike, regardless of the hazard of the particular chemical. Then, despite the many field problems encountered, the program was described from Sacramento as highly successful and showing the excellent cooperation of all in agriculture. Greater attention is now being given within the state both to problems of pesticidal soil pollution in relation to water quality and to recycling alternatives to land disposal of used pesticide containers.

III. Protecting the Environment from Agricultural Pesticides

This section makes some broad suggestions for reform of the present regulatory system. These should be considered as supplementation to, and in some cases elaboration of, the more specific changes suggested in the preceding section of this chapter. These broader suggestions are offered tentatively, since further study and discussion is needed. Four areas will be considered: inclusion in the "non-label" parts of the regulatory system of grower use of "non-injurious" materials; reforms in the sanctioning system in use for professionals in the pest-control business; possible reorganization of state and local government responsibilities for environmental protection; and basic restructuring of the manner in which pest-control advice is made available to and used by growers.

A) Grower Use of "Non-injurious" Materials

California has developed three focal points for control of the field use of agricultural pesticides: the registered label; the list of "injurious materials" and "injurious herbicides;" and the licenses required of professionals in the pest-control business. Label restrictions have long been a feature of both federal and state pesticide law, and cannot be entirely disregarded as a means for affecting the way in which pesticides are used. There is good reason to believe, however, that, standing alone, label restrictions bring much less control than the architects of the labeling system may have assumed, at least when label restrictions are intended to reduce a social cost and not merely the economic cost to the user of the material. In California, label restrictions seem to have become a reality some decades ago for professional pesticide applicators, for, once their business was brought under direct regulation by the state, violations of label restrictions raised at least the possibility of a sanction of some kind against their licenses. Now, however, these restrictions are acquiring increased importance to those in certain other phases of the pest-control business. This development has been brought about by the recent state requirements that recommenders of pesticides--the "pest control agents"--register in the counties in which they give advice, together with the fact that, like pest-control operators (applicators) and pesticide dealers, they will soon be required to have a state license.

Thus, occupational control over "professionals" has been one way of bringing home label restrictions to those working with pesticides in the field. The other major way in which this goal has been accomplished, and further use restrictions established and enforced, has been through the lists of injurious materials and injurious herbicides, with concomitant permit control in most cases. Nevertheless, these two historical patterns of regulatory activity have left an obvious and serious hole in the structure: neither touches the grower who uses "non-injurious" materials on his own property. He is subject only to the use restrictions on the label, and, as suggested, these are of very doubtful protection against social costs such as long-term environmental damage from misuse or overuse of pesticides. There is thus a pressing need, by one means or another, to subject growers to regulation comparable to that now exercised over professionals in the case of all materials and over all users in the case of injurious materials and injurious herbicides. This becomes particularly important when it is recalled that the two "injurious" lists have in fact grown on a very haphazard basis, that many so-called "non-injurious" materials are of a toxicity comparable to that of materials on one of the injurious lists, and that toxicity, whether acute or chronic, is not necessarily the only reasonable criterion for subjecting a pesticide to special use restrictions. Serious consideration should be given to determining whether grower use of non-injurious materials can best be controlled by putting all pesticides under some sort of permit system, by placing growers under licensing requirements similar or identical to those now imposed on the professionals, or by some other system.

B) Sanctioning Violations by Pest-Control Professionals.

We have described how "notices of warning" lead very infrequently to any kind of real administrative or judicial sanction against pest-control professionals, together with the apparent explanation: the attitude of "compliance is our goal--let's work with the industry." This pattern is not unfamiliar among administrative agencies with regulatory responsibilities, and there is no intent here to derogate the value of "education" of those subject to the often complex and detailed requirements of the law. Education is not enforcement, and administrative discretion in carrying out enforcement activity does not justify a lack of enforcement activity. Thus, it appears that a major change may be in order in sanctioning patterns for violations.

One possibility for change is simply more vigorous use of the sanctions already available: suspensions or revocations of county registrations, suspensions or revocations of state licenses, and prosecutions for acts that constitute misdemeanors or felonies. One inhibiting factor in the past seems to have been the twin beliefs that: a) court proceedings through the district attorney are appropriate in only the most serious cases, for this procedure requires extensive work in building a case and district attorneys are too busy with combating murder and rape to be asked to worry about various pesticide offenses; and b) formal administrative proceedings that may lead to suspension or revocation of a man's license are "too drastic" for most violations, which local officials consider to be "minor." Thus, the "slap on the wrist" provided by the notice of warning is generally considered the appropriate response when a violation is detected, although many officials state that individuals who are chronic offenders--as shown by a file full of notices of warning--will be subject to more serious action. In fact, it is difficult to find actual instances where further administrative proceedings have been taken simply because of an accumulation of warning notices over the years. In contrast, formal proceedings typically involve a single incident regarded by local and/or state officials as very serious (e.g., direct spraying of workers in a field with an organophosphate). Thus, when agricultural commissioners and inspectors throughout the San Joaquin Valley were interviewed, only one instance was found where a series of notices of warning had led to formal administrative proceedings (as opposed to the "office hearing," which amounts to calling an individual in for a discussion of his violation of violations).

It may be that some intermediate sanction should be developed for relatively minor violations that fall between the slap-on-the-wrist notice of warning and the license or registration proceeding, with its threat of loss of livelihood for weeks or months for an individual pest-control professional and his employees. Many agricultural commissioners in the San Joaquin Valley have reacted favorably to the idea of a system of "direct citation" similar to that now in use for violators of traffic laws. Under such a system, an agricultural inspector would have the authority simply to "write a ticket" for an individual found to be in violation. This would constitute a citation to appear in a local court and would obviate the necessity of going through the district attorney. Questions that should be carefully studied are whether such authority is in fact now available to agricultural commissioners and inspectors under California law, how best to acquire such authority (if now lacking), and the most appropriate means for exercise of such authority. Substantial strengthening and increased use of present or new sanctions for violations of existing controls for agricultural pesticide use offer considerable promise for much better control and, indirectly, enhanced protection of the environment as well as of public and occupational health and safety and the growers/consumers themselves.

C) Possible Reorganization of Responsibilities for Environmental Protection.

The rationale for formation of the Environmental Protection Agency was, at least in part, the notion that no single agency should be charged with the responsibility for both promoting the interests of a given industry and regulating that same industry. A further thought was that all or most major segments of the federal government engaged in environmental protection work should be brought together in a single agency. Thus, activities in pesticide regulation of the U.S. Department of Agriculture were transferred to the Environmental Protection Agency. Organization on such a basis is "functional" in terms of environmental protection but also involves "fragmentation" from other functional viewpoints, e.g., the concept of dealing with agriculture in a coordinated, comprehensive way through a single agency. Nonetheless, the federal reorganization was apparently considered justified by the difficulties created by promotion/regulation tensions, by existing splits in related authority (as between USDA and the FDA), and by the high priority now given to environmental protection.

Exactly these same kinds of problems exist at the state and local levels, although the State Department of Public Health in California has less authority over residues in food products than the Federal Food and Drug Administration had prior to formation of the Environmental Protection Agency. It therefore follows that consideration ought to be given to state and local governmental reorganization for environmental protection similar to the federal reorganization. Such change has in fact been proposed at the state and regional level, although it is remarkable that one major recent effort along these lines omitted direct pesticide use control from the elaborate list of functions (establishment of environmental goals, conservation and development planning and control, radiation control, air pollution control, coastal-zone protection, water-quality control, and solid-waste management) that were to be transferred to a State Environmental Quality Board and eight regional environmental quality boards.[114] Yet, unless the proposed regional entities are established and well equipped with funds, the same kind of reorganization may ultimately be necessary at the local level as well. Such reorganization probably cannot take place immediately, and must be done very carefully. What now exists is a reasonably active and well-trained field force of agricultural inspectors who have responsibility for field enforcement of controls on the use of agricultural pesticides. These inspectors are subject to the same production/regulation tensions that were well-noted publicly when federal pesticide-regulation responsibilities were transferred from USDA to EPA. Indeed, these tensions are not unique to the pesticides area, for agricultural commissioners and inspectors in several other areas enforce laws and regulations "against" the agricultural interests they also promote. Still, they are at least in the field and in active contact with most segments of the agricultural world affected by pesticide use controls. To shift these local regulatory responsibilities to a regional board without providing that board with the same kind of field force could in fact decrease the effectiveness of the regulatory system. It is notable, for example, that enforcement of the Safety Orders for Agricultural Operations is now inadequate, and that the Division of Industrial Safety, charged with this enforcement responsibility on a regional basis, has been very seriously understaffed for many years. More encouraging are other examples of field enforcement through regional offices, such as that carried on by the Department of Fish and Game. But the danger of "going regional" without providing adequate support must be emphasized, along with the crucial significance of maintaining a large and active field force of inspectors. There is now a "field presence" not only at the county level in California, but also at the level of districts within each county. But agricultural district inspectors perform a variety of functions aside from pesticide regulation; unlike the situation in the federal government, there are no cadres of pesticide specialists scattered through the local governments who can simply be brought together under one roof for ready coordination of policy and gradual development of an integrated approach to preservation and enhancement of environmental quality.

Much of the rationale for creation of the Environmental Protection Agency within the federal government is sound also for local government as well as state and regional government. Agricultural commissioners and inspctors, closely tied to the needs of agricultural producers, often do have attitudes toward pesticide use that differ fundamentally from attitudes of officials engaged in resource protection. These differing attitudes are often disclosed most clearly in terms of the perceived "burden of proof" when allegations are made that a particular pesticide is causing or may cause certain environmental damage, or in a different approach to making some rough kind of cost/benefit analysis when some environmental damage occurs or is threatened. These abstract considerations seem well-supported as to the San Joaquin Valley by past developments in the Azodrin-wildlife problem and present developments in ground disposal of used pesticide containers. In the absence of establishment of a new state agency for comprehensive environmental protection on a regional and/or local basis, serious consideration should be given to the possibility of achieving increased environmental protection through reorganization within the present framework of city and county government. What must be stressed, however, is the fact that implementation of such reorganization will be far more difficult at the local level than at the federal level and that an absolutely primary requirement is maintenance and strengthening of the extensive regulatory field presence already developed in California agriculture.

D) Reform of Pest-Control Advice to Growers

The fourth and final broad suggestion for reform concerns the way in which growers obtain pest-control advice. Such advice now comes from many sources: neighbors; farm organizations; articles in various publications; University of California "Pest Control Recommendations," published each year for each agricultural county; University of California Agricultural Extension farm advisors and pest-control specialists; a handful of consulting entomologists; and salesmen for agricultural chemical companies. The last source, the "fieldmen" associated in one way or another with a chemical company is of the greatest importance. The company represented may be the manufacturer or the basic chemicals, but it is more often a local company engaged in formulation work. This local company will generally act as the primary distribution point for the products of a particular major (national) chemical company, although it can obtain all pesticides available in the market place. Many of these local companies are "integrated" operations, engaged in formulation, sales, and application work (increasingly, both ground and air application), and thus are able to offer a "package" of services to their grower customers. Such an integrated firm may need several kinds of state or local authorization, e.g., a pest-control operator's license with county registration(s), a pesticide dealer's license, and county registration for each of its employees who makes pest-control recommendations.

In previous and present reform of state control over the occupational categories involved in pesticide usage, it has been assumed that what is desirable is "more of the same." In other words, with a history of a license requirement for the applicators, the appropriate regulation for dealers was deemed to be a license requirement, and now the same process is being undertaken for professional recommenders of pesticides. The fundamentally sound premise of "pesticide-use-by-prescription-only" comprises three basic ideas: 1) that pesticides, or at least certain pesticides, should be applied only with the approval of a "professional" recommender; 2) that competence for pest-control recommendation should be attested by a license; and 3) that licensed professional recommenders should be independent in judging a particular method of pest control, weighing ALL costs and benefits--individual and social, short-term and long-term. Although the third idea is in many respects the most important, recent reforms in the regulation of different phases of the agricultural pest-control business in California[115] are limited to the first two of these three ideas.

In considering the critical importance of independence in pest-control recommendations, one must keep in mind the dominance of salesmen of chemical companies as a source pf pest-control advice. Most of the "pest control agents" now registered in California are closely associated with a chemical company, either as an employee or some kind of "commission agent." Agricultural salesmen should be well-trained, highly experienced, and of integrity. They must do their "field-checking" for their grower customers in a careful fashion and may in particular instances advise against chemical control even where some pest problem exists. Such a salesman must sometimes resist heavy pressure from a customer who is anxious to spray regularly and heavily upon sighting the first of a particular pest in the field. The classic high-pressure hit-and-run encyclopedia salesman image thus does not generally apply to chemical sales personnel in the San Joaquin Valley.

Nonetheless, very strong pressures operate on the pesticide sales force. Pesticide use recommendations by agricultural chemical company salesmen are not and cannot be independent, nor can the "prescription only" philosophy ever be fully implemented while the recommendation and sales phases of pest-control are not separated from one another. In earlier years many agricultural chemical salesmen worked on a straight commission basis, and today many work on a salary-plus-commission basis or are eligible for some kind of bonus or similar financial reward when their sales exceed a fixed quota. Their own initial training has come from the chemical company in many cases, and any "refresher" course may be under the same auspices. Repeat business, of course, depends on satisfying the grower, who is well aware of increased direct costs through chemical control, yet neither the grower nor the salesmen operate in a milieu which encourages sensitivity to environmental damage of a long-term nature. Their time perspective is a short one, and their cost/benefit analysis is entirely individual.

Thus, "prescription only" requires that professional (and presumably technically competent) advice must come from an independent source. Judgment in this area is as important as the technical competence required to pass a licensing examination. Ultimately, the recommenders must be entirely separate from the chemical companies engaged in the manufacture, formulation, and sales of pesticides. This may require salesmen to establish themselves as independent consultants on pest control, providing advice directly to the grower, with their fee probably related to the acreage supervised. A few former salesmen now do such consulting work in California and their ranks seem to be increasing slightly. If the sound premise of a "prescription only" approach is seriously accepted by those with policy-setting and law-making responsibilities in the state, they must go beyond licensing, which at best only ensures a certain level of technical competence. They must tackle the more difficult problem of independence, which involves a fundamental restructuring in the manner in which growers obtain pest-control advice.

E) Pesticide-Use Law Reform and Environmental Protection

Of the four broad suggestions presented in this section for reform in California pesticide law, only the third is put directly in terms of environmental protection and enhancement. Even that suggested reform is not directed specifically at protection of the aquatic resources of the San Joaquin Valley. This section therefore ends by making clear the assumptions underlying the approach taken. These are twofold.

First, it is assumed that the many "discoveries" of environmental pollution in recent years point to the conclusion that the precise nature--and sometimes even the general nature and magnitude--of various kinds of chemical pollution of the environment cannot be foreseen and may not even be suspected for a long period, even by those who are most critical of the widespread release of different chemicals into the environment. This is of particular importance with toxic chemicals such as pesticides, used in the first place because of their power to kill living organisms. Where a particular hazardous consequence from pesticide use can at a given moment in time be perceived and documented, present machinery allows knowledge of this consequence to enter into the judgment-making process and to influence determinations as to continued use of the material. At the same time this process often appears unduly slow, cumbersome, and weighted in favor of continued use of the material. Some of the specific reforms suggested above should bring substantial change in situations where hazardous consequences are perceived and documented. In so many cases, however, the pattern has been one of "use first, full knowledge of consequences later." Since this characteristic is probably inherent in the situation no matter how much research is done prior to use, there is a strong case for the position *that from an environmental point of view the less pesticide used in agriculture the better*. Without minimizing either the present importance of pesticides to those engaged in agriculture or the necessity to consider carefully the potential impact of reduced pesticide usage on matters of general interest such as food prices, there is a strong case for seeking a generally reduced level of agricultural pesticides--whether "hard" (persistent) or "soft" (nonpersistent), whether highly toxic to man or relatively nontoxic to man--in order to reduce the risk of serious unforeseen long-term damage to the environment.

In seeking this reduction, environmentalists should have two strong allies. First, within the field of entomology itself or, more precisely, "economic" entomology, there is growing interest in the concept of "pest management" as opposed to "pest control." The concept of pest management stresses the use of particular methods of pest control in a *system* aimed at keeping pest damage below an established level of economic damage. The emphasis is on detailed knowledge of the agri-ecological situation in a particular field and on decision-making on particular pest-control methods (whether chemical, cultural, biological, or other) in a broad context of crop management. The particular "kill" potential of a given chemical material receives relatively less emphasis than in traditional "pest control," and is considered to be only one of many mortality factors of possible influence on pest infestation in a field.

A second ally for the reforming environmentalists may be found in those responsible for the protection of public health and safety. For many decades, the public-health aspect of pesticide use control centered on the consumer of food products that receive pesticides at some stage. There are at present, of course, numerous groups who oppose the use of any pesticide on any food product at any stage, and there is also considerable controversy over both the adequacy of particular federal or state pesticide residue tolerances and the extent to which violations of these tolerances are detected and enforcement vigorously pursued. In California, the public-health emphasis has now shifted to concern over occupational health, particularly of those frequently exposed to pesticides in the field, e.g., pilots, flagmen, ground-rig operators, and field workers. At times a switch in chemical materials may appear environmentally advantageous but occupationally disadvantageous. An example is the general trend to substitute organic phosphates (often more acutely toxic to those exposed occupationally, but thought to be less persistent and therefore less hazardous environmentally) for chlorinated hydrocarbons (more hazardous environmentally in that biological magnification causes an impact further up the food chain, but generally less acutely toxic to those in immediate contact with the materials). If, however, the overall quantities of toxic chemicals used in agriculture can be reduced, both those exposed occupationally and the physical and biological environment stand to gain.

A second assumption underlying the broad reform suggestions of this section concerns the relation between regulatory controls of "input" (application) and of "output" (waste). One reading of the present situation in the

San Joaquin Valley, at least regarding protection of the aquatic environment, might be that control of agricultural wastes should receive the prime emphasis: 1) the Central Valley Water Quality Control Board should give higher priority to "non-point source" agricultural pollution;[116] 2) establishment of waste discharge requirements for individual growers or for irrigation and other special districts should proceed; and 3) these requirements should be vigorously enforced. Each of these developments is probably desirable, and there are some indications that the policy direction to be supplied by the State Water Resources Control Board will be toward total elimination of surface runoff from California farms. Farmers would thus be required to use water-application systems compatible with elimination of surface runoff of irrigation waters, or ponding systems would be needed on farms, or other measures would be required.

These would be important steps in waste control, but it would be unfortunate if they were the sole response by water-quality officials to problems of environmental degradation created by pesticides in agriculture. The process will be slow, water-quality officials will have significant difficulties in establishing standards, and the approach will remain piecemeal. The work will presumably be coordinated with officials who have studied the effects of agricultural pesticides on wildlife, but the waste-control steps that seem most likely may not deal extensively with subsurface drainage and soil pollution through pesticide concentration. Consequently, progress in rationalizing and improving the system for controlling inputs is assumed here to be even more important than progress in direct regulation of agricultural wastes with some pesticide content. This second assumption explains the emphasis given above to restructuring the manner in which growers receive advice on pesticide use, to the development of closer regulation of grower use of noninjurious materials, and to the need for more rigorous sanctioning of violators of pest-control regulations. Even the suggestion for possible governmental reorganization is keyed in part to "input" control, for that would place different hands on the control levers at the top. Unlike many areas of environmental pollution, the field of pesticide pollution has an apparatus for control of the inputs that make the wastes that create pollution. Failure to recognize and use this existing apparatus would be a serious mistake in future environmental reform efforts.

IV. Important Litigation Concerning Pesticides in the San Joaquin Valley

By no standard can "important" litigation be considered to include the typical crop-damage claim, settled through an insurance adjuster or otherwise, or sometimes decided by trial. Such claims in the San Joaquin Valley over the past several decades probably number in the hundreds, and they have been disposed of within the framework of ordinary private law principles dealing with negligence, trespass, and strict liability. The manner in which these principles have been applied on occasion raises some important questions, some treated in the legal literature,[117] but there have apparently been no pioneering pesticide-crop damage decisions in the San Joaquin Valley.

Brief mention should be made, however, of pesticide or pesticide-related litigation of three sorts. First, there has been litigation during the past several years over the question whether the work reports filed with agricultural commissioners by pest-control operators are available to members of the public under California's Public Records Act. Upon the advice of the State Department of Agriculture, most agricultural commissioners have treated these records as closed to the public except in very limited circumstances, e.g., where information from the records has been required by a physician in order to treat a specific case of pesticide poisoning. The confidential status of these records has been justified primarily on the ground that they contain trade secrets. Several years ago, persons associated with the United Farm Workers Organizing Committee sought general access to these applicators' "spray reports" in the office of the agricultural commissioner for Kern County, one of the eight San Joaquin Valley counties. This access was initially denied, and several local firms engaged in pesticide application work went to court to enjoin the agricultural commissioner from disclosing the contents of the applicators' work reports in his custody. The court issued the injunction on the theory such reports are excepted from the Public Records Act by its own terms.[118] Since that injunction was issued, the same question has been litigated in Riverside County, which lies outside the San Joaquin Valley. A comparable decision by the trial court was rendered and appealed, the State of California intervened on appeal on behalf of those seeking public access to the spray reports, and the Court of Appeal for the Fourth District, in Uribe v. Howle, held that reports of pest-control operator's application work are not exempt from public disclosure under the Public Records Act.[119] The Supreme Court of California denied review of this decision, which is presently regarded by the Department of Agriculture as a final disposition of the point. Although this question itself does not affect pesticide use patterns directly, it may in some instances affect the ease with which litigation may be brought regarding environmental damage.

A second area for brief note is litigation over farmworker health and safety with regard to pesticides. California Rural Legal Assistance (CRLA), an OEO-funded law firm that practices "poverty law" in rural parts of California, has been engaged in some very broad pesticide legal activity. In March 1970 an administrative complaint covering a series of pesticide matters was filed with the Director of Agriculture.[120] This complaint led to a conference between the director and an attorney with CRLA. Certain administrative actions since taken--in particular the setting of worker re-entry times for a number of crops--may have resulted partially from this complaint. Apparently no court action has ensued directly from this complaint, although CRLA has unsuccessfully sought in court to ban the use of organic phosphates, as well as to require the Farm Labor Service to consider pesticide hazards in providing farm labor to growers. This litigation by CRLA has been state-wide in character, not tied to any problems specific to the San Joaquin Valley.

Finally, the third kind of pesticide litigation to be mentioned here is what is apparently the first "environmental" lawsuit over pesticide use in San Joaquin Valley legal history. This suit was brought by Friends of the Earth and Defenders of Wildlife, who seek to prevent the Fresno County Department of Agriculture from use of the Compound 1080 in rodent control.[121] In September 1971 a temporary restraining order was obtained against use of Compound 1080 by the county, but at a subsequent hearing a preliminary injunction was denied and the county thereafter completed its program of aerial dissemination of the material. An amended complaint by the plaintiffs, filed in November 1971, seeks permanently to enjoin use of Compound 1080 by the county.

Notes, Chapter 8

1. Fielder, statement to the U.S. House of Representatives Select Subcommittee on Labor (San Francisco, November 21, 1969), as quoted in California Department of Public Health Community Studies in Pesticides, Report for 1969 at 123.

2. Sections 12811-12828, Agricultural Code Annotated of the State of California, adopted March 15, 1967, effective November 8, 1967, with 1971 Pocket Supplement covering legislation through the regular session of 1970 (Deering 1967, 1970) (hereinafter cited as "Cal. Ag. C."). Section 12811 excepts from the license requirement sellers of raw materials to a manufacturer and sellers of any economic poison already registered by the manufacturer or wholesaler. On the requirement of a license for manufacture as well as for sale, compare Cal. Ag. C. §12811 with Cal. Ag. C. §12815. See also Cohen, "Department of Agriculture," in Nestle (ed.), California Administrative Agency Practice (California Continuing Education of the Bar, California Practice Book No. 49, 1970), p. 292: "No economic poison may be manufactured or sold in California unless a license for sale of the product has been granted..." [Emphasis added.]

3. See generally on federal registration Rohrman, "The Law of Pesticides: Present and Future," 17 Journal of Public Law 351, 356-360 (1960); the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), 7 United States Code §§135-135k; and Reorganization Plan No. 3 of 1970, §2(8)(i), which transfers jurisdiction for the administration of the FIFRA from the U.S. Department of Agriculture to the Environmental Protection Agency.

4. Cal. Ag. C. §§12501-12671.

5. Cohen, supra note 2 at 295 (California pesticide tolerances "closely follow" federal tolerances). The California tolerances are established by regulations of the Director of Agriculture, Cal. Ag. C. §12561, and are published at Title 3, §2490 of State of California, California Administrative Code (hereinafter cited as "Cal. Admin. C.").

6. Legislature of the State of California, "Interim Hearings of the Assembly Committee on Agriculture on Pesticide and Worker Safety Laws," transcript of hearings November 23, 1970, December 9, 1970, and December 10, 1970, at 59 of November 23 hearings. A recent unpublished study estimates that about half the pesticide products registered in California are not in interstate commerce and thus are now exempt from the FIFRA's requirement of federal registration. McGowen, "California State Department of Agriculture--Pesticide Registration" (November, 1971), p. 6. An estimated 65% of new product registrations, however, are of products not intended for shipment in interstate commerce. Ibid.

7. Cohen, supra note 2 at 290, estimated 800 chemicals at a time when there were over 14,000 product registrations.

8. This percentage is based on information informally obtained from the Department of Agriculture. One computer analysis showed approximately 38% of 1970 registrations to be of products approved for agricultural use.

9. Cal. Ag. C. §12812, as amended in 1970, imposes the $40 fee. Previously this section provided for an annual fee of $100 per licensee. This fee covered

ten products, with an additional fee of $10 per product. Cal Ag. C. §12813 provides for considerably lower fees for those who manufacture economic poisons which do not exceed a total retail value of $2,000 per year. In November 1970 an official of the Department of Agriculture estimated the higher fees would lead to a decline to about 10,000 product registrations. Legislature of the State of California, supra note 6 at 61 of November 23 hearings. Information informally obtained from the department indicates there are now estimated to be between 10,000 and 11,000 product registrations in force.

10. Cal. Ag. C. §§12871-12872.

11. Cal. Ag. C. §12976 (formerly §12972) imposes these restrictions on the use of any pesticide by "any person in pest control operations."

12. Cal. Ag. C. §§12976 and 12971.

13. Cal. Ag. C. §12824.

14. Cal. Ag. C. §12825.

15. Cal. Ag. C. §12826.

16. Cal. Ag. C. §§14061-14063 (Compound 1080) and Cal. Ag. C. §§14091-14098 (thallium).

17. Cal. Ag. C. §14005.

18. 3 Cal. Admin. C. §2461. Twelve kinds of seeds treated with any of the listed mercury compounds are also listed as injurious materials, 3 Cal. Admin. C. §2461(f), as are conifer seeds treated with endrin. 3 Cal. Admin. C §2461 (g). Chemical compounds used to treat seeds for a wide variety of purposes are "pesticides" or "economic poisons" under California law. (The term "economic poison" is defined at Cal. Ag. C. §12753, and this term and "pesticide" are used interchangeably. Cohen, supra note 2 at 290. See also Cal. Ag. C. §11404.) Although technically the seeds, once treated with a pesticide, are not themselves considered to be a pesticide, they are considered to be a "material" subject to regulation under Cal. Ag. C. §14005.

19. 3 Cal. Admin. C. §2461.1.

20. 3 Cal. Admin. C. §2462.

21. Ibid.

22. 3 Cal. Admin. C. §§2463-2463.4. Cal. Ag. C. §14006 specifically provides for the regulation of use of injurious materials by permit.

23. Cal. Ag. C. §14007.

24. 3 Cal. Admin. C. §2463(b).

25. 3 Cal. Admin. C. §2448.

26. 3 Cal. Admin. C. §2450.

27. 3 Cal. Admin. C. §2451.

28. 3 Cal. Admin. C. §2451(d). The various "hazardous areas" are described at 3 Cal. Admin. C. §2449.

29. Cal. Ag. C. §14102. This prohibition or regulation is to be "pursuant to" the existing statutes on economic poisons and injurious materials.

30. Cal. Ag. C. §14101.

31. California Department of Agriculture, report (untitled, undated and unsigned typewritten report of six pages submitted to the California Legislature pursuant to the requirement of Cal. Ag. C. §14104 that the Director of Agriculture submit an annual report to the legislature on "the use of environmentally harmful materials, the control of these materials, programs leading to their elimination or the elimination of the injury caused, and his progress in improving the condition of the environment in relation to the use of such materials"). This report provides "a listing of the significant actions undertaken during the 1970 year." *Id.* at 1.

32. See Cal. Ag. C. §§11701, 11402 and 11403.

33. Cal. Ag. C. §11701.

34. Cal. Ag. C. §11704.

35. Cal. Ag. C. §11738 and 3 Cal. Admin. C. §3077. The regulations and licenses issued under them distinguish, by type of pest, among eight types of pest control. They also distinguish between air and ground application and among use of spray, dust, and fumigation. For the year 1971 over 1,300 Agricultural Pest Control Operator licenses have been issued.

36. Cal. Ag. C. §11709. For the year 1971 over 100 persons have obtained such a permit.

37. Cal. Ag. C. §11901.

38. Cal. Ag. C. §11738(c).

39. Cal. Ag. C. §11735(a).

40. Cal. Ag. C. §11737.

41. 3 Cal. Admin. C. §§3090-3098.

42. See Cal. Admin. C. §2465, which became effective in February 1970, for the requirement that the holder of an injurious materials permit file a use report "by the tenth of the month following the application," unless the material is applied by a licensed agricultural pest control operator and included in the operator's report. The record-keeping and reporting required of the licensed operators--for *all* pesticides used--are described at Cal Ag. C. §11733 and 3 Cal. Admin. C. §3090(g).

43. Cal. Ag. C. §12101. "Pesticide dealer" is defined at Cal. Ag. C. §11407.

44. Cal. Ag. C. §12106. For the year 1971 over 1,000 Agricultural Pesticide Dealer licenses have been issued, of which an estimated 300 are for branch offices of a given firm.

45. Cal. Ag. C. §12001.

46. Cal. Ag. C. §11406.

47. Cal. Ag. C. §11408.

48. Senate Bill 1021, enrolled by the Legislature October 20, 1971, and approved by the Governor October 29, 1971 (Chapter 1276). The sections of this act which repeal the present requirements for the registration of agricultural pest control agents and provide for state licensing and county registration of agricultural pest control advisers become effective on July 1, 1972. *Id.* at §22. However, these sections authorize the issuance through January 1, 1974, of a "provisional license" to an *applicant* for an agricultural pest control adviser license. Regulations are to establish "equivalent experience qualifications in lieu of education and examination for a provisional license as a pest control adviser up to January 1, 1974..." *Id.* at §5. During this interim period, practitioners will have the opportunity to attend workshops on pesticide use to be developed by the University of California in conjunction with the Department of Agriculture. *The Sacramento Bee*, "California Life" section, p. 15 (December 4, 1971). Applicants will be examined in one or more of seven categories of pest control. "Within each category, the exam will probe understanding of state and federal pesticide laws; pesticide problems; pest problems; host community problems; recognition of population dynamics; when to treat; build up of secondary pest problems; ability to choose alternate means of control; wildlife contamination; air and water pollution; proper timing of pest control methods...proper equipment, farm worker safety...and questions about many other areas which are yet undetermined." *Ibid.*

Other sections of Senate Bill 1021 substitute the term "restricted material" for the term "injurious material," provide a nonexhaustive list of six criteria to be used in the establishment of the restricted materials list, expand the list of specific matters with which restricted materials regulations may deal, and provide for permit control of all pesticides other than those on an "exempt" list to be designated by the Director of Agriculture. *Id.* at §§6-20. The provision in this bill that exempt materials "may be used without a permit provided that such use shall conform with the registered label or printed instructions," *id.* at §16, appears to pre-empt the area with regard to such materials, so that in the future counties will be barred from adopting for them permit or related control.

49. In addition, provisions for financial responsibility aim to assure the satisfaction of judgments against aircraft pest control operators. Cal. Ag. C. §§11931-11940.

50. Derived from California Department of Agriculture "Reports by California Counties (July 1, 1969 through June 30, 1970) [on the] Agricultural Pest Control Business (Inspection Program, Legal Action) [and on] Injurious Materials/Herbicides" (December 31, 1970).

51. 8 Cal. Admin. C. §§3298-3298.18.

52. 8 Cal. Admin. C. §§3298.15 and 3298.14.

53. The Porter-Cologne Water Quality Control Act, enacted in 1969 and operative January 1, 1970, constitutes Division 7 of the California Water Code (§13000 et seq.).

54. California Regional Water Quality Control Board, Central Valley Region, Interim Water Quality Control Plan (June 1971, two volumes).

55. Id. at vol. 1, VI-3. Volume one deals with the Sacramento River Subbasin and the Sacramento-San Joaquin Delta Subbasin.

56. Id. at vol. 1, VI-4.

57. These hearings, held jointly with the chairmen of the nine regional water quality control boards, took place in Los Angeles on February 18 and 19, 1971. Statements submitted to the hearings are available from the State Water Resources Control Board.

58. This committee has divided its work into four areas: dairy and feedlot wastes, poultry wastes, salt balance problems, and pesticide and fertilizer residues.

59. California Regional Water Quality Control Board, Central Valley Region, "Policy for the Control of Water Quality with respect to Solid Waste Disposal" (Resolution No. 69-216, adopted March 14, 1969) at 1. The board's earlier policy, which did not provide a systematic classification of solid waste disposal sites with corresponding limitations on the materials to be deposited therein, was established by "Policy for the Prevention and Control of Ground Water Pollution with respect to the Disposal of Refuse to Land" (Resolution No. 64-165, adopted September 18, 1964).

60. California Regional Water Quality Control Board, Central Valley Region, "Policy for the Control of Water Quality with respect to Solid Waste Disposal" (Resolution No. 69-216, adopted March 14, 1969) at 1.

61. California Fish and Game Code §5650(f).

62. Id. at §5651. Civil proceedings before the regional board are supplementary to any criminal proceedings which may be brought under §5650 of the Fish and Game Code. People v. Union Oil Co. (1969) 74 Cal. Rptr. 78, 268 C.A.2d 566.

63. California Health and Safety Code §39013. This section is found in Division 26 of the code, a division known as the "Mulford-Carrell Air Resources Act."

64. Id. at §39051.

65. Id. at §39430.

66. Id. at §39442(c). This exception is to specific restrictions imposed on discharges "from any single nonvehicular source of emission." The restrictions are written in terms of darkness and opacity. Id. at §39441.

67. 42 U.S.C. §§ 4321-4347.

68. California Public Resources Code, §§21100 and 21151.

69. Several of the interpretations included in the final three sections of Chapter 8 were first suggested by one or another of the various county and state officials interviewed in connection with the preparation of this chapter. The information and advice provided by these officials was of very great assistance in preparation of this chapter, but these officials are of course in no respect responsible for any errors of fact or interpretation which may appear herein.

70. California Department of Agriculture, supra note 31.

71. Id. at 4.

72. California Dept. of Agriculture, 1970. Pesticide use report, Jan.-June 1970. Sacramento, California.

California Dept. of Agriculture, 1970. Pesticide use report, 1970. Sacramento, California.

California Dept. of Agriculture, 1971. Pesticide use report, Second quarter 1971. Sacramento, California.

73. California Department of Agriculture, supra note 31 at 4.

74. California Department of Agriculture, "Order Amending and Adopting Regulations of the California Department of Agriculture Pertaining to Economic Poisons" (adopted December 2, 1971; filed in the Office of the Secretary of State December 6, 1971; to take effect on the 30th day after filing with the Secretary of State). The order provides that registration "for economic poisons containing mercury compounds for seed treatment shall be cancelled effective January 1, 1972," but it also provides for three exceptions when registration may by granted. These are for use to treat "breeders seed to insure adequate supplies of planting seed that will be free of those diseases that are controllable only by mercury compounds...seed to comply with requirements of other states and foreign countries specifying mercury seed treatment as a condition of entry... [or] seed for planting in specific areas of the state when the Director determines that an emergency disease condition exists in those areas." Id. at 1-2. These registration cancellations do not directly affect seeds already treated with mercury, see supra note 18, the planting of which is permitted through the spring 1972 season "in locations considered safe." Memorandum from Department of Agriculture (Chief, Agricultural Chemicals and Feed) to county agricultural commissioners (November 10, 1971) at 1. "As pheasant hunting season approaches, you are requested to closely supervise application of mercury treated seed in order to avoid hazardous residue levels in game birds." Ibid.

75. California Department of Agriculture, supra note 31 at 4.

76. Ibid.

77. See Cal. Ag. C. §14103, which requires the Director of Agriculture to consult with representatives of four other state agencies and with four "outside experts of his selection from the fields of agricultural, biological, ecological, and medical sciences" in "establishing criteria and regulations relating to environmental injury and protection."

78. See generally McGowen, supra note 6.

79. Cal. Ag. C. §12824.

80. See generally U.S. House of Representatives Committee on Agriculture, Hearings of February and March 1971 on the Federal Pesticide Control Act of 1971; U.S. Senate Subcommittee on Agricultural Research and General Legislation of the Committee on Agriculture and Forestry, Hearings of March 1971 on the Federal Environmental Pesticide Control Act; and the numerous bills presently pending which would replace the FIFRA or alter it in one respect or another.

81. H.R. 4152, S. 745.

82. Letter dated April 1, 1971, from John C. Hillis to Dr. Terry Davies, published in U.S. Senate hearings supra note 80 at 186-187.

83. Id. at 186.

84. Id. at 187.

85. Ibid.

86. Ibid.

87. Ibid.

88. McGowen, supra note 6 at 20-24.

89. California Department of Agriculture, supra note 50 at 2 (Agricultural Pest Control Business, Legal Action).

90. Ibid.

91. Ibid.

92. Ibid. The county statistics for the same period on the control of injurious materials/herbicides show 51 office hearings and zero prosecutions. California Department of Agriculture, supra note 50 at 3.

93. California Department of Fish and Game Federal Aid Project FWIR (Pesticides Investigations Project), "Azodrin Wildlife Investigations in California" (1967) at 4.

94. Ibid.

95. Id. at 1.

96. Ibid.

97. See Shea, "Cotton and Chemicals," 10 Scientist and Citizen 209, 212 (1968).

98. Id. at 216.

99. California Department of Fish and Game, supra note 93 at 15.

100. California Department of Fish and Game, *supra* note 93 at 13.

101. Department of Fish and Game (Manager, Region 4), Memorandum to All Wardens, Captains, Unit Managers (April 9, 1968) at 4.

102. *Ibid*.

103. See, e.g., Memorandum from Department of Fish and Game Warden Cochran to Captain Devers (October 8, 1968), which summarizes the author's opinions on Azodrin usage in eastern Merced County in 1968. The conclusions were based on contacts with two crop-dusting firms, several ranchers, and the Merced County agricultural commissioner's office.

104. Memorandum from Department of Fish and Game Chief of Operations to Regional Manager, Region 4 (May 2, 1969) at 2.

105. Memorandum from Department of Fish and Game Deputy Director to Regional Manager, Region 4 (July 24, 1969) at 1. The memorandum noted that Azodrin was the first pesticide ever to be placed on the injurious materials list "solely on the basis of its hazard to wildlife." *Ibid*.

106. Letter from Western District Manager, Shell Chemical Company, to all Azodrin insecticide distributors and Central Valley pest-control operators (August 1, 1969) at 1-2. An official statement of these criteria, in slightly different form, was appended to a memorandum from Department of Fish and Game Regional Manager, Region 4, to various unit managers and wardens (July 24, 1969).

107. Author not indicated, internal report in draft form entitled "Summary Azodrin Program in Region 4--1969 Fresno County" (undated; located in Department of Fish and Game Region 4 files).

108. The "Use and Directions for Applications" on cotton portion of the Azodrin label now includes the following: "California--San Joaquin Valley only--AZODRIN 5 must not be applied later than 2 weeks after initiation of bloom and definitely not after July 15 in order to avoid injury to wildlife." See Azodrin label in appendix to Shell Chemical Company, *1971 Shell Pesticide Directory*.

109. Dietz, "Disposal of Used Pesticide Containers--Current Efforts to Correct This Problem" (speech given at a meeting June 22, 1971, of the Pacific Branch, Entomological Society of America) at 2. See also Western Agricultural Chemicals Association, Newsletter No. 0083 (January 11, 1971).

110. California Department of Agriculture, press release (March 31, 1971) at 1-2.

111. Dietz, *supra* note 109 at 3.

112. California Department of Agriculture summary of comments made in response to a questionnaire, "Used Pesticide Container Cleanup." This summary appeared as an attachment to a memorandum dated March 29, 1971, from a departmental inspection services official to the regional coordinator who coordinated this program.

113. Memorandum from Chief, Bureau of Vector Control & Solid Waste Management, Department of Public Health, to various local and state agencies (July 27, 1971) at 3-6.

114. California Legislature, 1971 Regular Session, Assembly Bill 1056 (introduced March 18, 1971). This bill was passed by the California Assembly on July 26, 1971, but "held" (and thus effectively killed) in the California Senate Committee on Governmental Organization.

115. See note 48 *supra*.

116. The basis for such activity was laid over five years ago when the Central Valley Regional Water Quality Control Board co-sponsored a major symposium on the subject, but little implementation followed. See Doneen (ed.), *Agricultural Waste Waters* (Proceedings of a Symposium at Davis, California, April 6-8, 1966) (Report no. 10, University of California Water Resources Center).

117. See van den Bosch, "Insecticides and the Law," 22 *Hastings L.J.* 615 (1971). and see generally Annot., 37 A.L.R. 3d 833 (1971).

118. *Atwood Aviation, Inc. v. Morley*, No. 103595, Superior Court for Kern County. The order granting a preliminary injunction was issued March 27, 1969. A temporary restraining order had been issued August 22, 1968. Despite the decision in *Uribe v. Howie*, *infra* note 119, an appeal filed in this case is being defended. Oral argument is on the calendar of the Court of Appeal for the Third District for December 20, 1971.

119. *Uribe v. Howie* (1971) 96 Cal. Rptr. 493.

120. California Rural Legal Assistance, Administrative Complaint to the Director, State Department of Agriculture (March 3, 1970), filed on behalf of eight farm workers. See also *In re Arturo Gonzales et al.*, Petition for the Declaration of Pesticide Emergency in the State of California and for the Establishment of Pesticide Safety Program, a petition filed by California Rural Legal Assistance with the Directors of the State Department of Agriculture and the State Department of Public Health (March 5, 1970).

121. *Friends of the Earth, Inc. v. County of Fresno*, No. 151035, Superior Court for Fresno County.

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